Order and Diversity Within a Modular System for Housing: A Computational Approach

by
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ABSTRACT

This thesis introduces elements of a methodology to achieve order and diversity in the systematic design of street facades within a modular system for housing. In its context both order and diversity refer to the spatial arrangement of architectural elements; order emphasizes repetition, whereas diversity emphasizes variation. The study addresses on one hand, the limitations of designers, design practice, and existing design theory principles in the achievement of diversity, and on the other, the opportunity provided by shape grammars, the use of evaluation rules, and the computer to develop a methodology that overcomes these limitations.

The study starts by presenting a modular system developed for housing. Then it presents a set of experiments designed with the goal of discovering designers limitations to generate diversity and their perception of it. These experiments use a computer program developed to trace the design process of the experimental subjects. Results suggest that limitations in diversity are due to designers psychological tendency towards order. Three different perceived manifestations of order are identified: logic order, orderliness, and balance. Orderliness is shown to be closely related to diversity through repetition, and as such are referred to as orderliness-diversity. Based on the experimental results three algorithms are then presented: one for orderliness-diversity, and two for balance. A shape grammar and a computer program for generating facades are then developed based on the rules of the modular system and the rules developed by one of the experimental subjects within the system. In order to guarantee order and diversity, the three developed algorithms are then proposed to be used as evaluative rules of the designs generated by the shape grammar.

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I am especially grateful to my wife for having supported me during the last six months at the cost of her own work, and to my parents for encouraging me to finish this study when they need me the most.

Table of Contents

7. The Discussion

Appendixes 313

"The architect should be equipped with knowledge of many branches of study and varied kinds of learning, for it is by his judgment that all work done by the other arts is put to test. [...] Let him be educated, skillful with the pencil, instructed in geometry, know much history, understand music, have some knowledge of medicine, know the opinions of the jurists, and be acquainted with astronomy and the theory of the heavens."

Vitruvius, The Ten Books on Architecture

1. Introduction

Industrial and demographic growths during the last two centuries have caused serious environmental and housing problems and have challenged architectural production. Shantytowns have proliferated and become part of the landscape in many countries throughout the world. Although according to authors such as John Turner, they *are not a disease* (Turner 1968) but constitute a viable way for people to provide for their own housing. They have often been criticized by their chaotic appearance. In an attempt to solve such problems, designers have developed rationalized systems aimed at providing a consistent framework for the mass-production of built artifacts. I, myself, got involved in the development of a modular system aimed at solving the serious housing problems in Portugal. However, the use of such systems has been rather limited and has generated a lot of dissatisfaction due their extensive use of repetition as a mean for industrialization. In fact, although the possibility of generating diverse houses was a goal of such systems their use was translated into monotonous and repetitive street environments. The interest in diversity is not only motivated by the desire to satisfy a psychological need, but also by the necessity to provide customized housing to a diverse population.

This thesis is, thus, concerned with housing street facades and has three main goals. First, it aims at understanding why designers seem unable to use modular systems to generate diverse facades. Second, it aims at discovering how diversity is perceived. Finally, it aims at searching for a methodology to overcome designers difficulties to generate diverse and customized designs.

In order to accomplish these goals two experiments were done. Both experiments are protocol studies (Akin, p.24), that use a computer program specially developed to trace the design process of the experimental subjects called the Design Tracer. The subjects are asked to design diverse designs either out of abstract elements or out of a given set of facade elements that are part of the developed modular system.

The experimental results suggest that among the principal factors that prevent designers from generating diverse designs are limitations of current design media, and a psychological tendency towards order. In the context of this study order refers to the spatial arrangement of elements. The experiments identify three different perceived manifestations of order: logic order, orderliness, and balance. Logic order is a result of the need of designers to perceive a logical generation of the design form. Orderliness is shown to be related to diversity. It describes the features of an arrangement of elements emphasizing repetition, whereas diversity emphasizes variation. Since variation and repetition describe the same feature of an arrangement of elements, orderliness and repetition are referred to as orderliness-diversity. The experiments suggest a way of measuring orderliness-diversity, that can be used as an evaluative rule in the generation of designs. Balance is either related to the visual weight of the elements that form a design—vertical balance, or to the sequential variation of the attributes of those elements around a central value—horizontal balance. By using an analogy with tonal music for horizontal balance, and a gravity metaphor for vertical balance, an algorithm for each type of balance is developed based on the experimental results.

The computer is presented as a way to overcome both the current design media and the designers' limitations to generate diverse facades, and therefore a computer model for a program that generates diverse and ordered facades is proposed. This model uses both a shape grammar (Stiny and Mitchell, 1978; 1980) and evaluation rules and is called Street Facade Generator. Among the main reasons for using a shape grammar are its abilities to encode the rules of modular systems, the rules defined by designers within such systems, and the ability to use both rules to generate diverse designs. In addition, it guarantees some logic order, and some orderliness. However, since a shape grammar is based on proscriptive rules, its ability to generate diversity without compromising order has a limit. Thus, the use of prescriptive evaluation rules for order allowing the use of a more open shape grammar with the ability of generating more diverse designs.

The evaluation rules used for order are the algorithms developed in the experiments. The specific grammar is based on rules defined within the developed modular system by one of the experimental subjects. However, other grammars can also be developed based on other systems and other designers, using as a research technique a protocol study in the way used in this thesis.

Section 2 of this thesis describes the previous research that led to its development. First, it describes the context in which evolved the concern for mass-production, order and diversity. Then, it describes the main features of the modular system devised to overcome these concerns. Finally, it points out the problems that arose with the use of such a system, mentioning other systems with similar concerns.

Section 3 discusses whether the failure to generate diversity using modular systems is due to flaws of the system or to an inability of designers, concluding that the latest is more important. Finally, it discusses the possibility of using the computer to overcome such flaws, and aspects of such use.

Section 4 outlines the hypotheses initially raised to explain designer's difficulties to generate diversity, which were: designer's sense of order, memory limitations, the need to operate with constraints, the tendency to treat designs as a whole, time constraints in architectural practice, and the lack of methodology and design theory to overcome the problem.

Section 5 describes the two experiments devised to study designer's behavior when asked to produce diverse designs.

Section 6 specifies the type of results gathered and where they can be found in the appendixes.

Section 7 discusses the results of both experiments in separate sections. It is organized in such a way that each section presents a sub-argument. If the experimental results provide some answers for the problems stated, these answers are ideas that the experimental lens helped to identify, rather than factual demonstrations. Accordingly, in the discussion of the results we introduce other examples in order to illustrate some of the points.

Section 8 summarizes the conclusions of the previous discussion.

Section 9 describes the Street Facade Generator. First, it explains what a shape grammar is and why it can be used as a solution to generate diverse designs within the system, and it describes the particular shape grammar developed in this thesis. Then it points out why a shape grammar is not enough, explaining its limitations, and how they can be overcome by the use of evaluation rules. Finally, it describes the computer program developed to encode the rules of the shape grammar, and how it can be transformed to integrate evaluation rules.

In conclusion, the aim of this thesis is to illustrate how existing research techniques and design theory principles can be used together to develop a methodology to overcome our main concern with order and diversity, rather than developing a practical application or a general computer model.

Nevertheless, I believe that the use of computer models based on a shape grammar and evaluation prescriptive rules, like the one suggested, is suitable for other design contexts in which there also is the need to respect certain "viewpoints" and the need to guarantee a broad range of possible designs solutions.

2. The Research

My research falls into two distinct parts. The first is concerned with the solution for an architectural problem, and the second is concerned with the problems of the solution. First, I will explain what the initial problem was, then I will describe the solution devised, and finally, I will address the problems of the solution.

2.1 Initial problem: mass production of housing in Portugal

Concerns: mass production, order and diversity

My initial research was concerned with the housing situation in Portugal, and it aimed at mass-producing housing, avoiding chaos and uniformity but creating diversity and order.

Mass-production was a requirement due to the dramatic housing problem in Portugal, which has persisted despite the efforts to overcome the situation. The housing problem emerged in the sixties when a strong industrialization occurring at that time led to an increase in the urban population. The problem was aggravated by the massive return of people from the colonies during their independence movements in seventies. Recently, a broad-circulation newspaper pointed out that the country still lacks about *half a million dwellings*. By using mass-production, we were following the concerns of the Modern Movement to bring industrialization to architecture as a way of meeting growing housing needs.

The housing shortage of the last decades and the inadequacy of the formal sector to provide affordable housing in sufficient numbers led to the proliferation of informal settlements characterized by their chaotic appearance. This appearance was due to the lack of organization among the various households, but also to the introduction in the market of new and industrialized materials and paints, rather different from the traditional ones. The availability of new materials and paints and the desire to break up with a past of poverty led people to use them to express their improved economical status. All these factors contributed to make the informal settlements look very different from the old ones (Figs. 2.1 and 2.2). The lack of spatial and aesthetical order became, thus, a national concern, and so it became also an important research requirement.

Fig. 2.1
Obidos, Portugal
Traditional settlement

Fig. 2.2
Portugal, 1980s
Informal settlement

The concern for diversity was prompted by not only the proliferation of materials and paints, but also by two other factors. First, it was also due to the need to the satisfy the housing needs of an increasingly diverse population. Recent statistics confirm that the social composition of the Portuguese population has become more heterogeneous during the last years. In fact, the number of households that fall out of the traditional family, (mother, father, and two children) has increased during the last years. Social diversity has also increased due to the proliferation of new life-styles brought up by urbanization and economic development. The other factor to influence the concern for diversity was the existence of an aesthetical and psychological need for diversity. The existence of such need diversity, has been pointed out by several authors. Rudolf Arnheim, for instance, says in his essay *Entropy and Art*:

> *Arthur O. Lovejoy, in his classic monograph on the principle of plenitude, has traced through the history of Western thought the idea that the universe, in order to be worthy of the conception of God, had to contain the complete set of all possible forms of existence. (...) The arts as a reflection of human existence have always and spontaneously lived up to this demand of plenitude.* (Arnheim, 1971)

Then he quotes E. Y. Eisenck to explain that plenitude is achieved by

> *(...) a "maximum of stimulation" drawing from the nervous system "the maximum amount of energy".*

Diversity is, thus, a psychological requirement. The existence of technological, social and psychological needs for diversity turned it into an important aspect of the research developed.

In conclusion, the research was aimed at finding a way of mass-producing housing. Therefore, emphasis was placed on repetition, rationalization and coordination, as the means of achieving the best cost/quality ratio for spatial quality. Nevertheless, despite recourse to repetition, there was an intention to provide customized housing. We were, thus, moving away from traditional mass-production. Moreover, we were also concerned with balancing the diversity required by customization with the order required to turn an urban environment into a harmonious whole where it would be pleasant to live.

2.2 The solution: a modular system

Due to the need to achieve flexibility, customization and diversity and to conform with production constraints where standardization was an issue, the solution devised consisted of a modular system. Since the system was made up of modules, these could be combined in different ways to meet the many and varied conditions. A brief description of the system developed is given below.

2.2.1 Conception

Module is the basic concept of the system. A module can be either abstract and be called *element,* or physical and be called *component.* An element is the module manipulated in design, whereas a component is the module manipulated in construction. The system has, thus, a dual character: on one hand, it is a design system, on the other, it is a building system.

The system assumes three different steps of development. First, at a high level of abstraction, the principles of a general system taken into account. Second, at an intermediate level, specific design and building systems for a certain context, and the principles of a specific application of the specific systems. Third, at a lower level of abstraction, the application of a specific system to a specific context. A path to the solution of a specific design problem would be completed once these three steps, diagrammed below, were also completed.

Levels:

High	General concept	---------	Modular system
Medium	Specific system	---------	Specific system
Lower	Case Study	---------	Specific application

The translation of the general concept into a specific system and the translation of this into a specific application implies the freezing of some variables and, therefore, an increasing degree of definition. Thus, one might develop different specific modular systems. The initial separation of the general concept from a specific technology allows the development of specific systems that use different technologies and various degrees of industrialization. Within each system, we can in turn, develop different specific applications, following the design rules of a specific designer. I developed a modular system which is described below, and then, I used this system to develop a specific application based on the rules of a specific designer, which is presented at the end of this thesis.

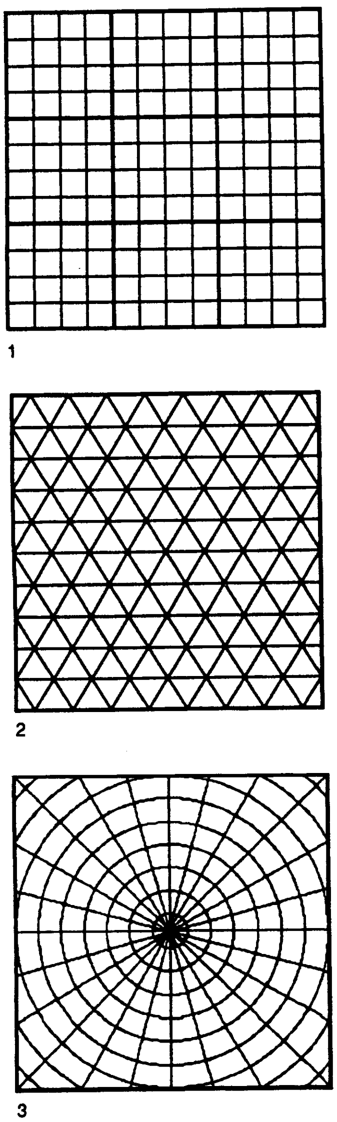
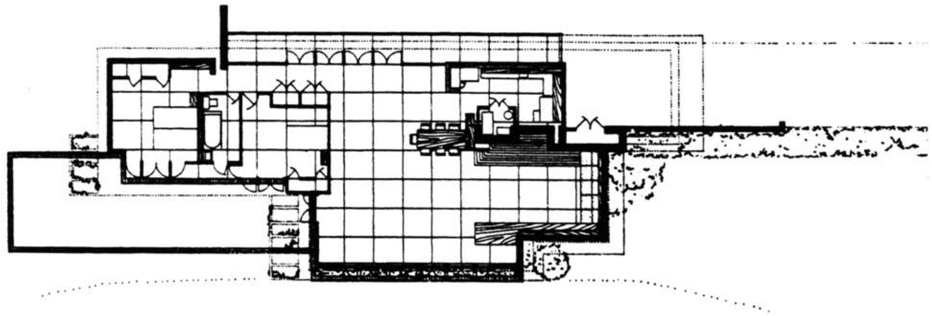
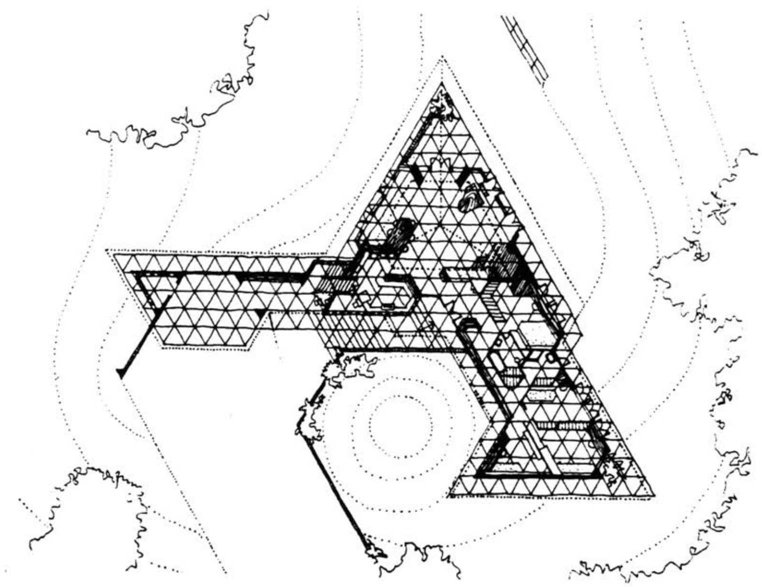


Fig. 2.3
Different types of basic grids: orthogonal (1), triangular (2), and concentric (3)

2.2.2 Grids

The system is based on the existence of three different grids. The first consists of the "field" on which the modules are put together, establishing the rules of composition and the metrics—the basic grid. This grid also represents the basic common standard (Fig. 2.3-1). Thus it guarantees the dimensional coordination of the design and building modules. Although the specific system developed uses an orthogonal grid as a basic grid, other systems can use other types of grids such as the ones shown in Fig. 2.3-2 and 3. Frank Lloyd Wright, for instance, used different grids in the design of his Usonian houses (Fig. 2.4).





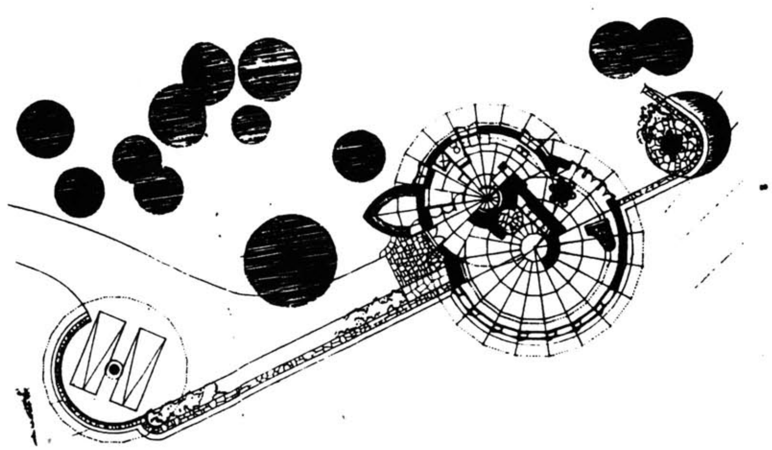


Fig. 2.4
Frank Lloyd Wright Usonian Houses are based on different kinds of grids. From the top to the bottom: Winkler-Goetsch house, based on an orthogonal grid (a). Palmer house, Michigan, 1950, based on a triangular grid. Friedman house, New York, 1950, based on a concentric grid

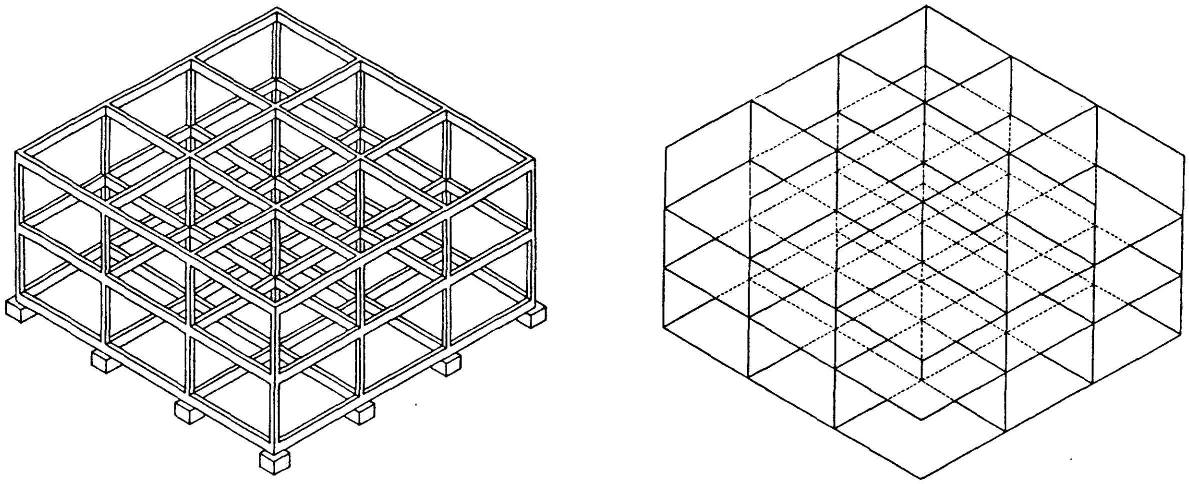


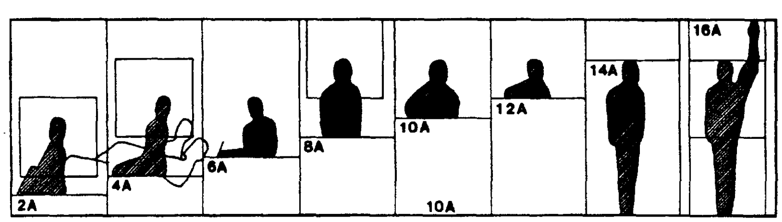
Fig. 2.5
The structural grid (left), and the spatial grid (2)

The second grid, is a multiple of the former and it represents the structure—the structural grid. A reticulate structure of the type: pillar, beam, slab, is a possible variation of that structural grid (Fig. 2.5, right). The third grid, is related to the previous two, and it provides the spatial modules of composition—the spatial grid (Fig. 2.5, left).

2.2.3 System of anthropomorphic proportions

The *system of anthropomorphic proportions* regulates proportion by relating the dimensions of modules of higher levels to the dimensions of modules of lower levels, and regulates scale by relating the dimensions of all the modules to the human body. The use of such anthropomorphic system facilitates modular coordination, and thereby it allows prefabrication. The series used for the specific system developed is shown in Fig. 2.6, and its geometrical implications on the design of the structure and the opening system is shown in Fig. 2.7.

Fig. 2.6
System of anthropomorphic proportions



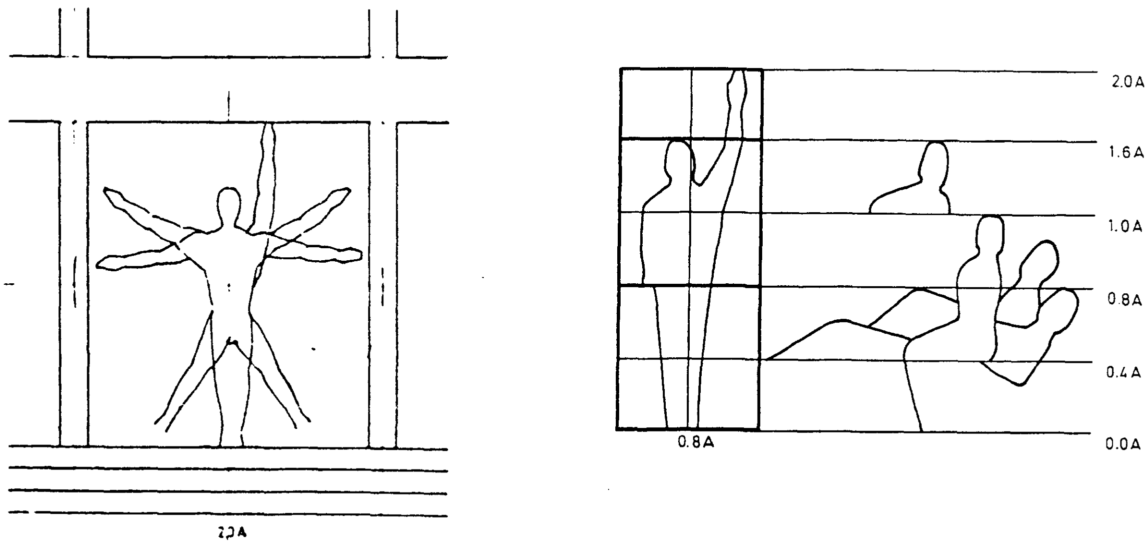


Fig. 2.7
Anthropomorphic proportions of the structure (left), and of the exterior opening system (right)

2.2.4 Subsystems

The system is made of two different types of modules: structural modules, and infill modules. Table I shows the main modules of the system developed.

Table I
Main elements of the system

Module	Instance
Structural module	pillar, beam, slab
Outer wall module	opaque panels or with openings for windows
Partition wall module	movable or fixable
Service module	a conglomeration of different appliances
Vertical communication module	interior or exterior stairs or ramps
Outside span element	to incorporate in a broken outer wall module
Inside span module	can be seen as a broken partition module
Cover element	terrace or roof
others	guard rails, cupboards, balconies, verandahs..
Finishings	different types and degrees of finishings

For each of these modules there is a corresponding specific sub-system, with its own functioning scheme. Fig. 2.8 is shows the modular composition of a facade according to the developed specific system using elements of different subsystems. Each subsystem is governed by two kinds of variables: constraining variables (climatic, urban, and human) and, dependent variables, specific for each system (position of an element in the grid, color, etc). The way how some of the dependent variables can vary in each system, and the corresponding ability to generate different architectural artifacts is illustrated in Figures 2.9 through 2.14.

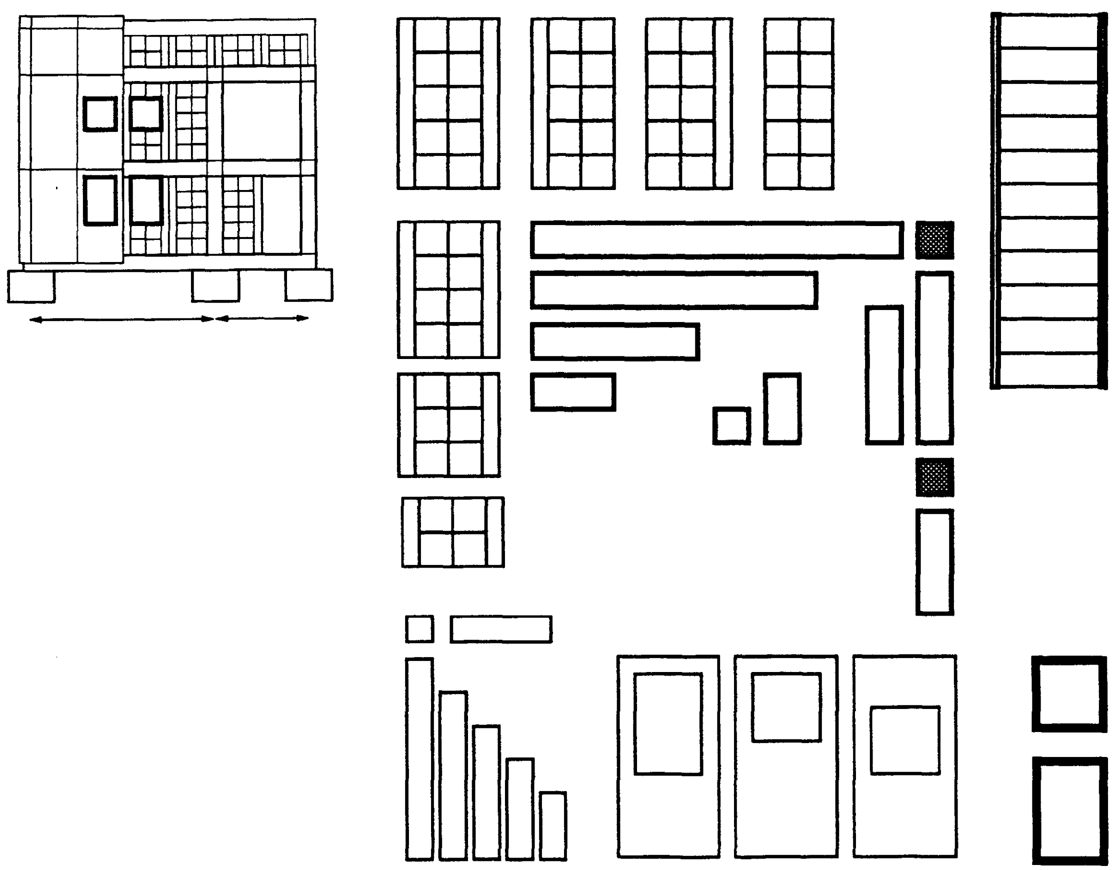


Fig. 2.8
Modular composition of the facade

Variations of the Variable Exterior Walls Position

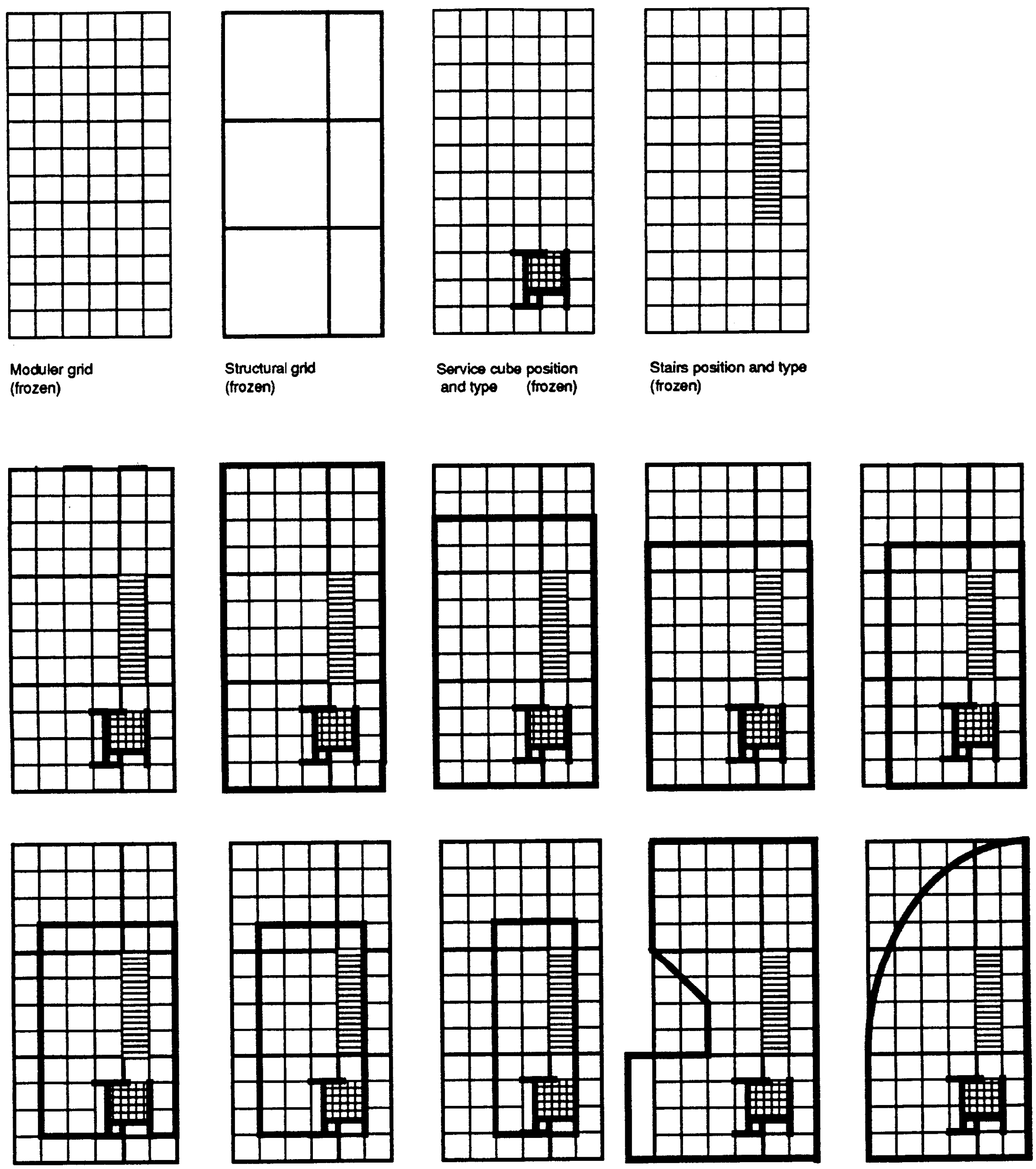


Fig. 2.9
Exterior wall subsystem.
Variations with variable position on plan

Variations of the Variable Partitions Walls Position

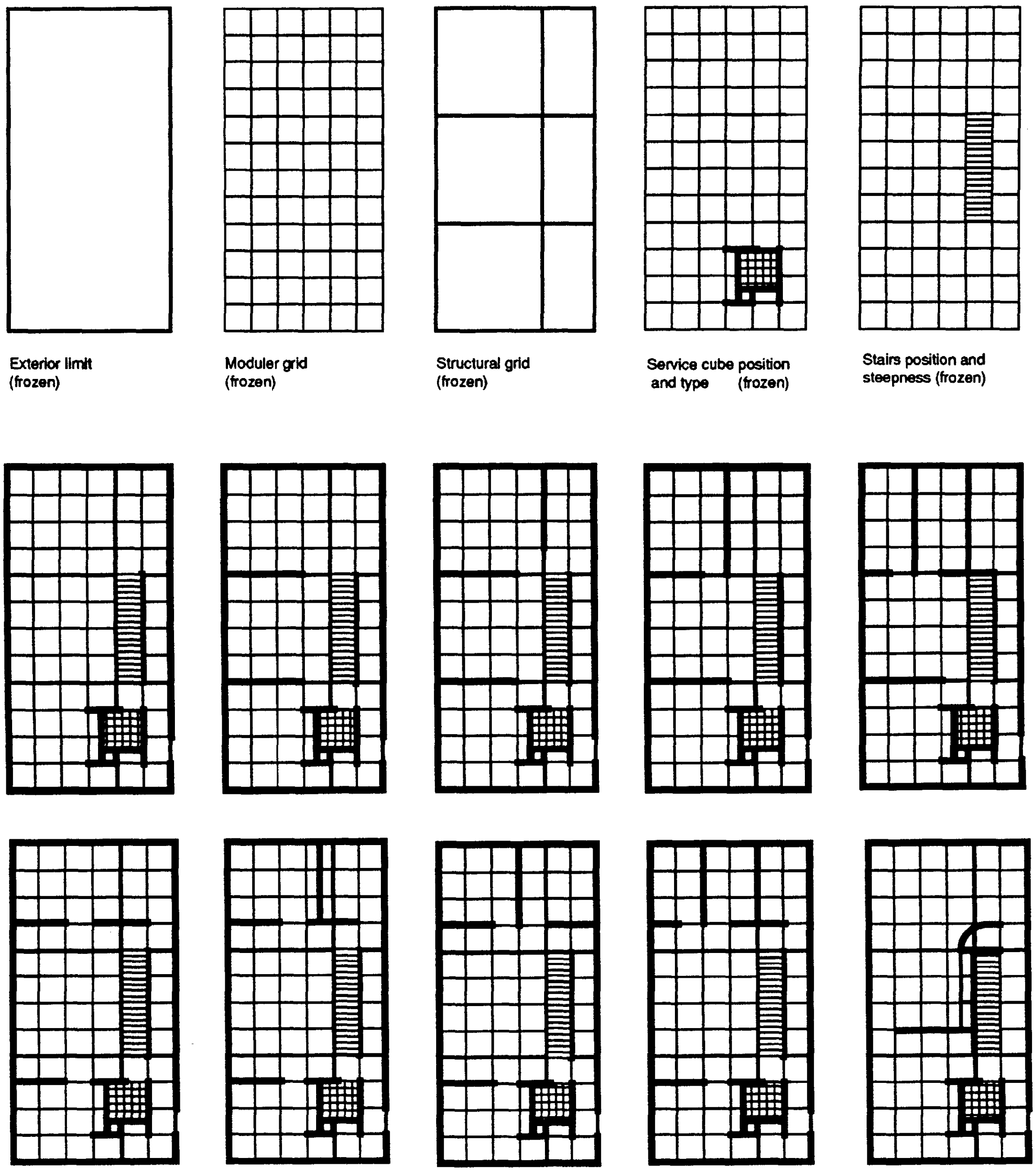


Fig. 2.10
Partition walls subsystem.
Variations with variable position
on plan

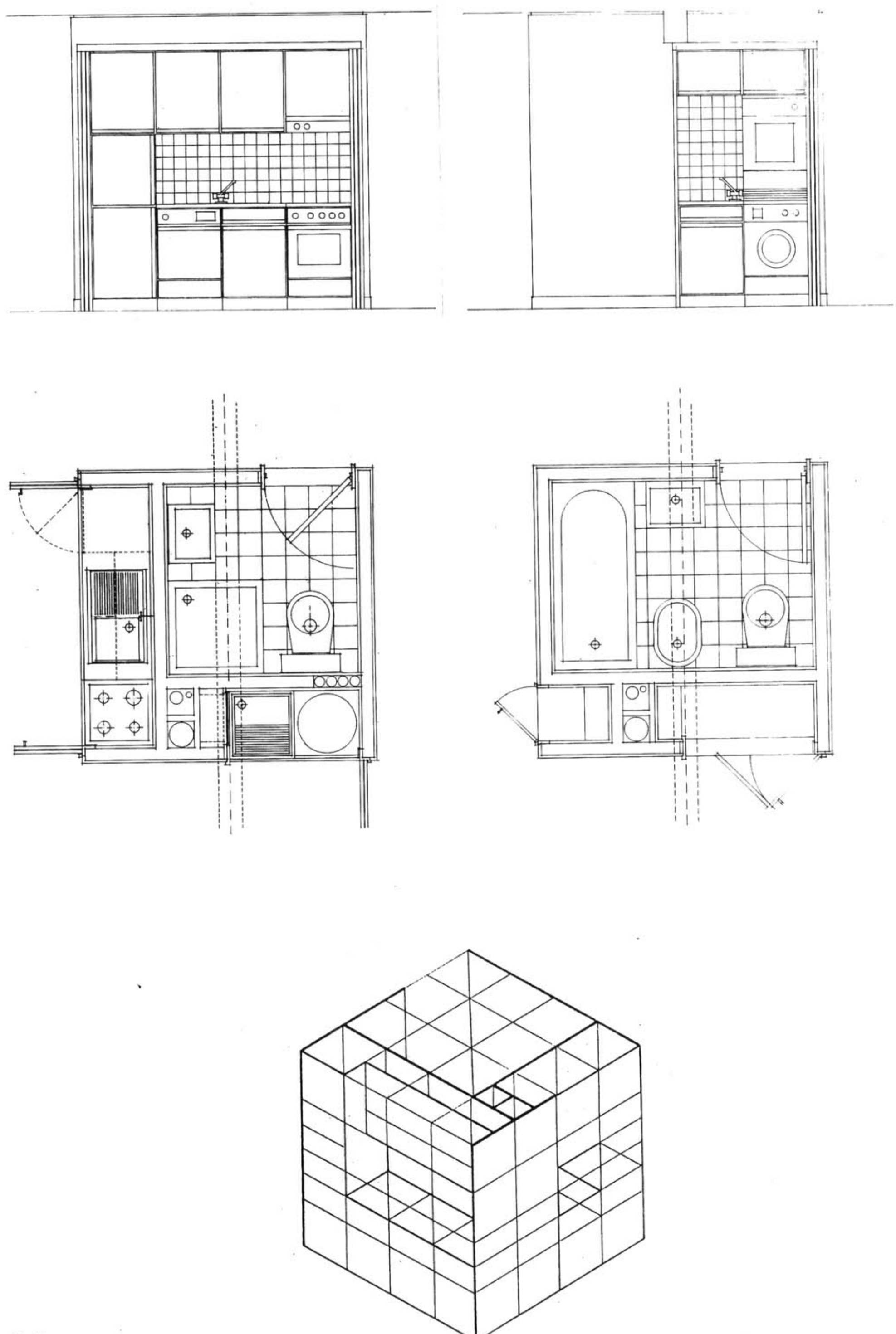


Fig. 2.9
Service core subsystem.
Two different types, and modular composition of an instance

Variations of the variable service cube position

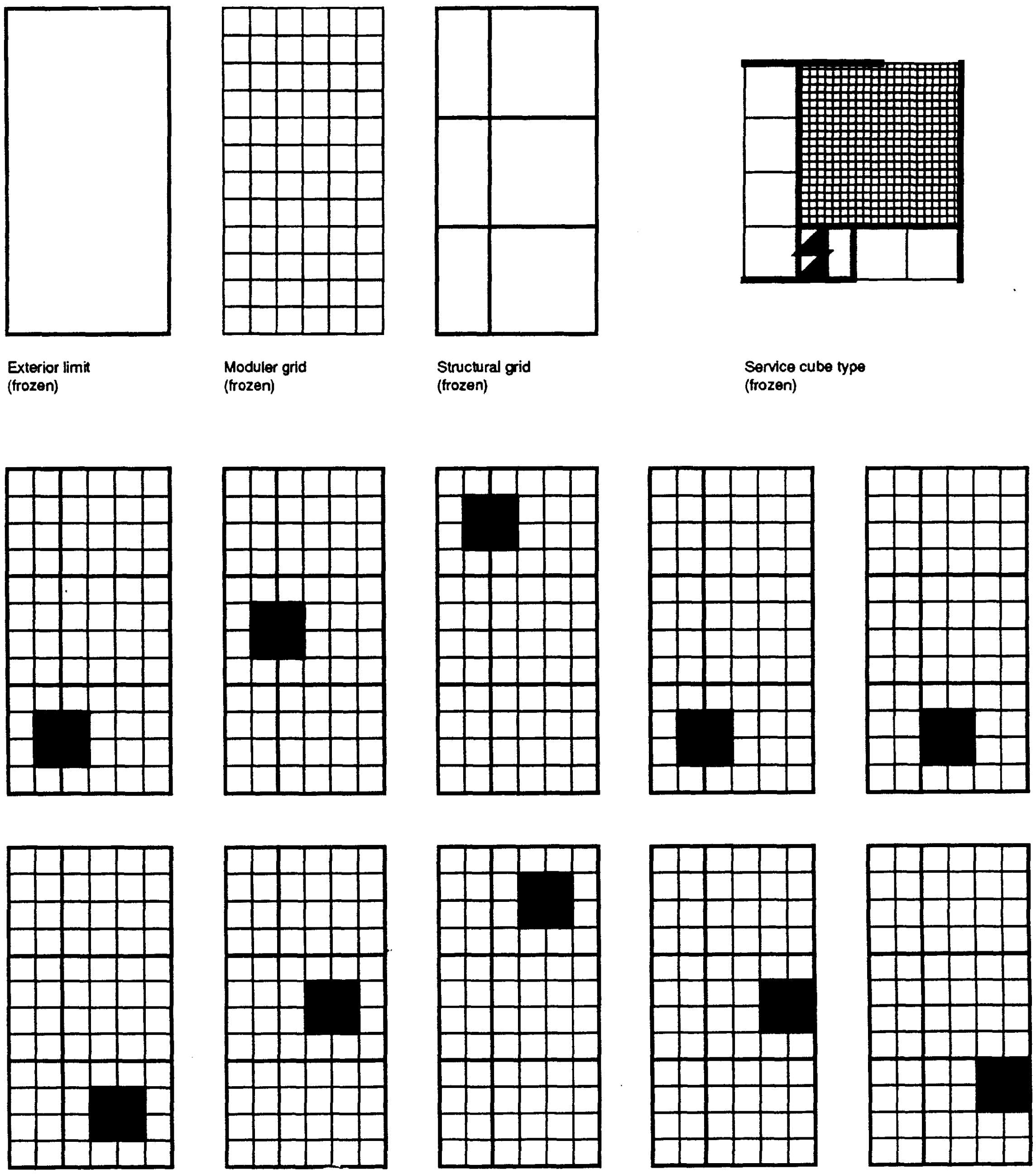


Fig. 2.12
Service core subsystem.
Variations with the variable
position on plan

Variations of the Variable Stairs Position

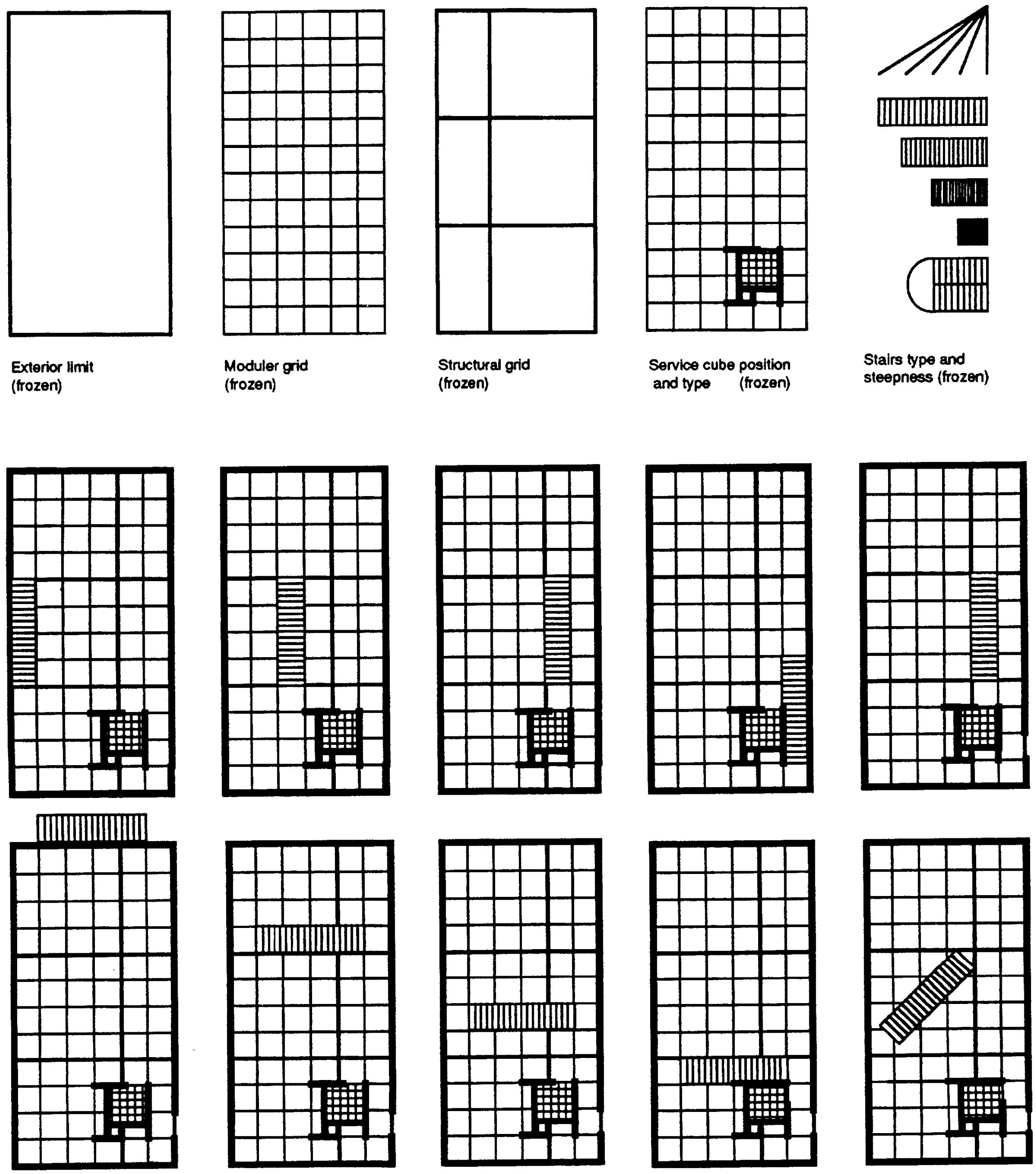
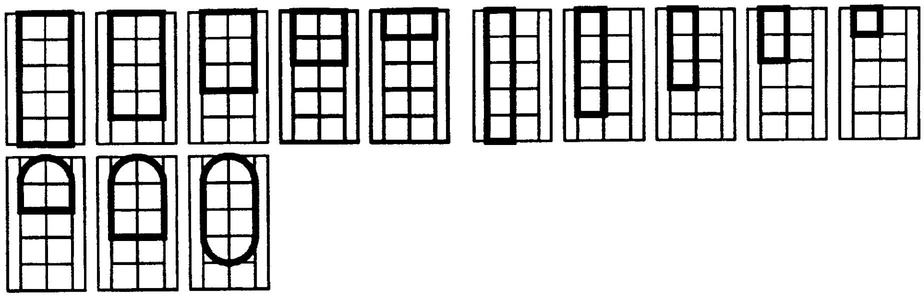


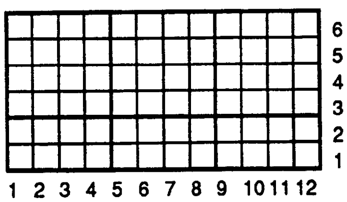
Fig. 2.13
Interior stairs subsystem.
Variations with the variable position on plan

Variables of the Exterior Openings Subsystem

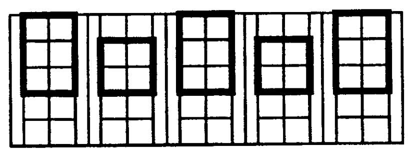
Form and dimension



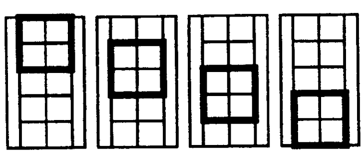
Position on plan



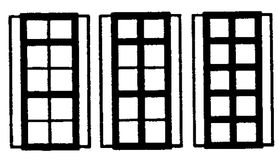
Association



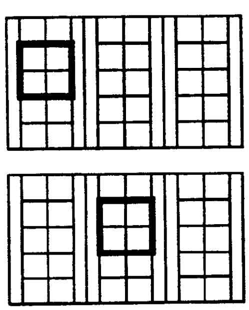
Position relatively to the floor



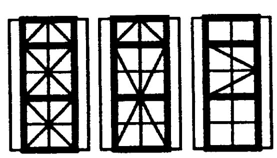
Design



Position on the facade



Opening mode



Jambs and sills
- brise-soleil, shutters...

Color
- black, white, yellow, blue, green,red,...

Material
- iron, wood, aluminum, plastic,...

Repetition

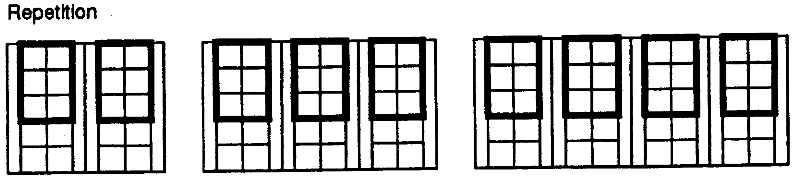


Fig. 2.14
Exterior openings subsystem.
List of variables

2.2.5 Modular scale and the use of levels

Given the characteristics of the system it is possible to establish a modulation scale with different degrees, where each element of the scale is obtained by a combination of the elements of the preceding level(Fig. 2.15).

We can draw a parallel with nature and think about the composition of matter where the atom is the basic element. The atoms join together and form molecules which, in turn, can join and form more complex structures, and so forth, until eventually living organisms are produced. The parallel between the two modulation scales could be as diagrammed below:

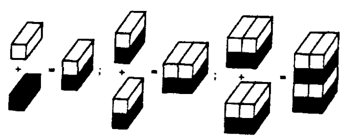
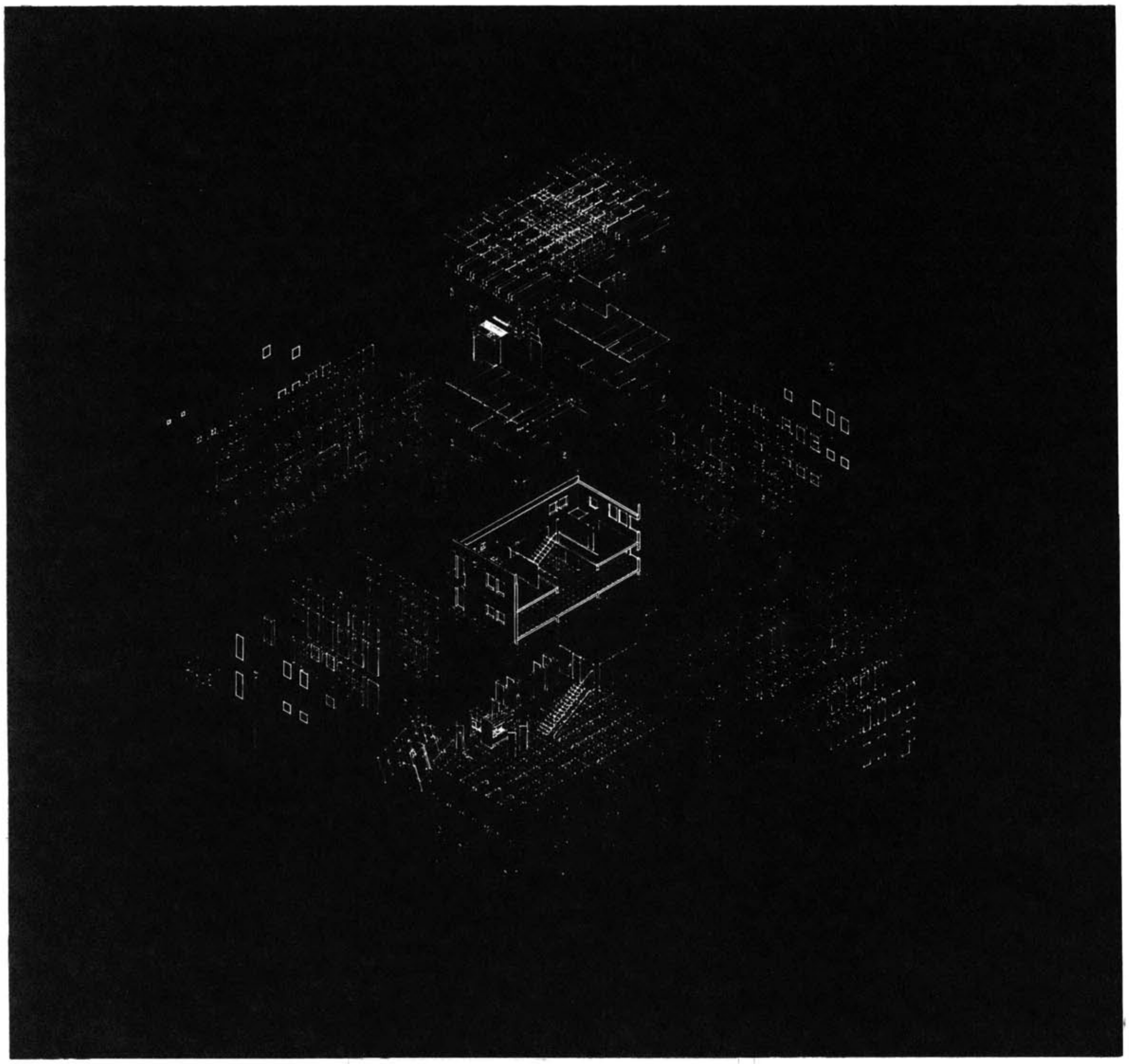


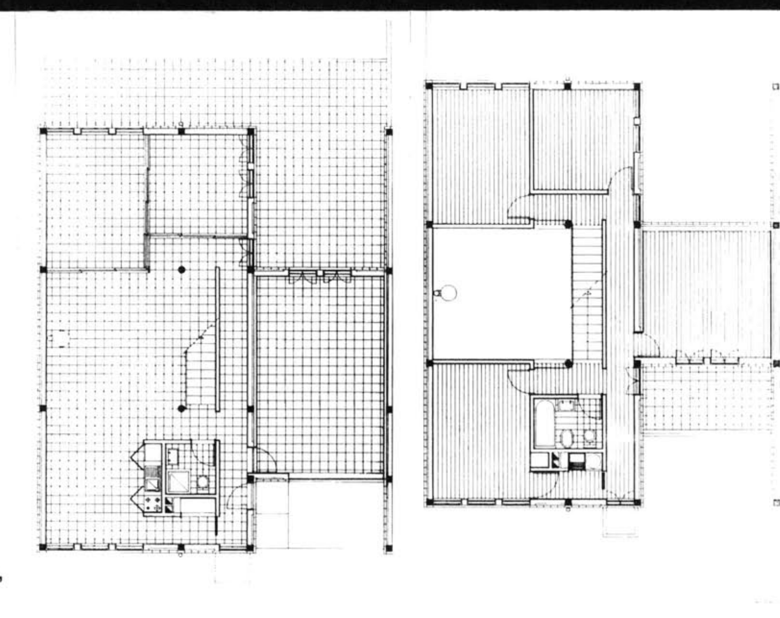
Fig. 2.15
The combination of modules of a lower level into modules of higher levels

SUBSUBMODULE-------------	PROTONS
SUBMODULE -----------------	ATOMS
MODULE -------------------------	MOLECULES
ROOMS ------------------------	CELLS
DWELLING ------------------	ORGANS
BUILDING ---------------------	BEING
BLOCK ------------------------	GROUP
NEIGHBORHOOD ----------	COMMUNITY
TOWN ------------------------	ECOSYSTEM

In both scales, the modules of a specific layer, are combined to generate modules of the next layer in the scale. The combination of modules within the modular system developed is illustrated in Figures 2.16, 2.17, and 2.18.

Underlying the modular scale there is a hierarchy. When working at certain level a designer will consider primarily the modules pertaining to that level, although the manipulation of modules of other levels is not excluded. For instance, an urban designer works mainly at the building and block levels, where buildings are the main units of composition, but that might imply defining or redefining some decisions of lower levels. For instance, changing the position of the house in the lot (Fig. 2.19), might affect the position of its interior partition walls, or the position of its windows and doors.





2.16
The modular scale.
From the components to the building: by combining the different components we obtain, different dwellings

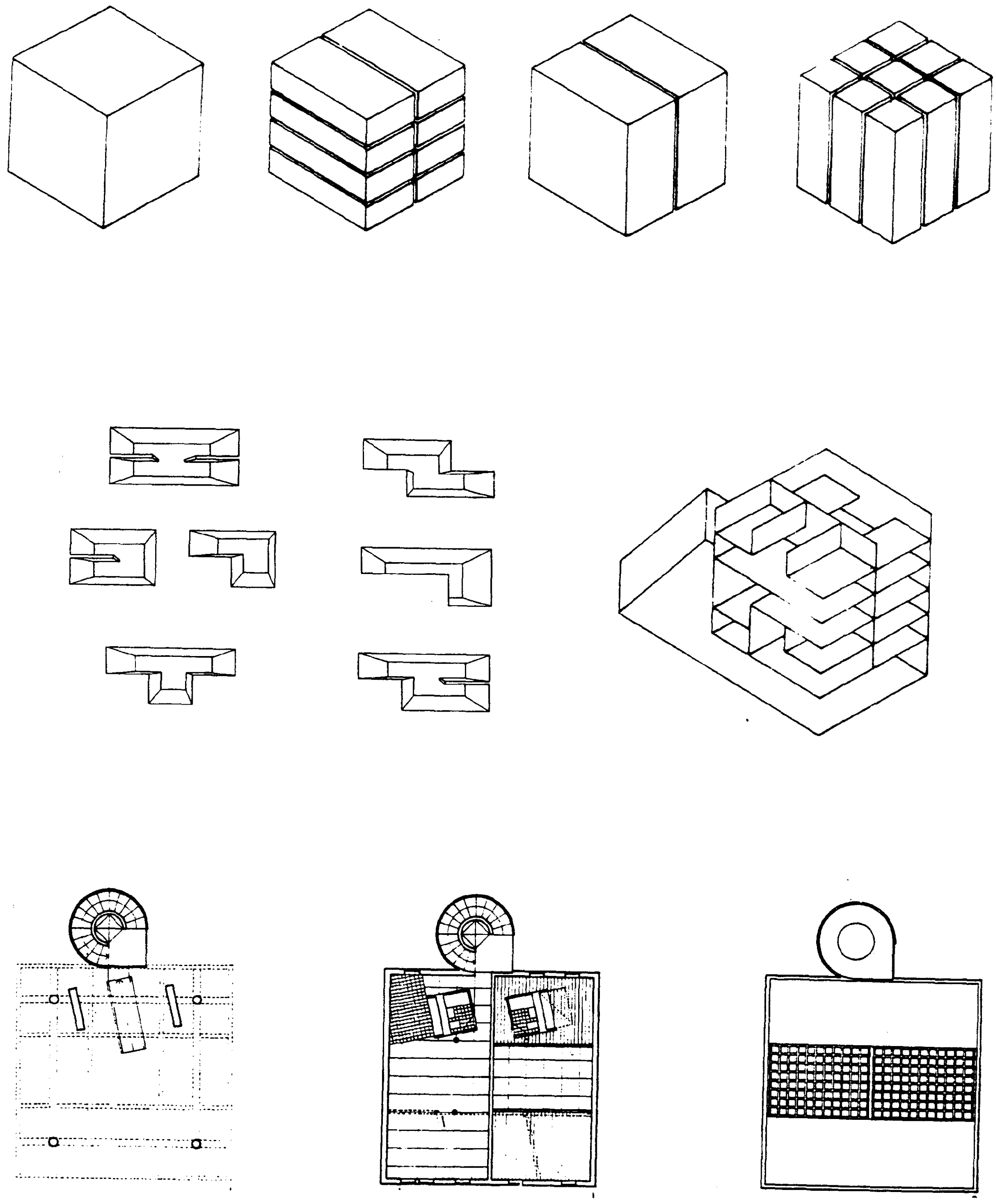


Fig. 2.17
The modular scale
From the dwelling to the building: by different associations of the various cells we obtain different buildings

Combination of the House and Annex Elements into Streets

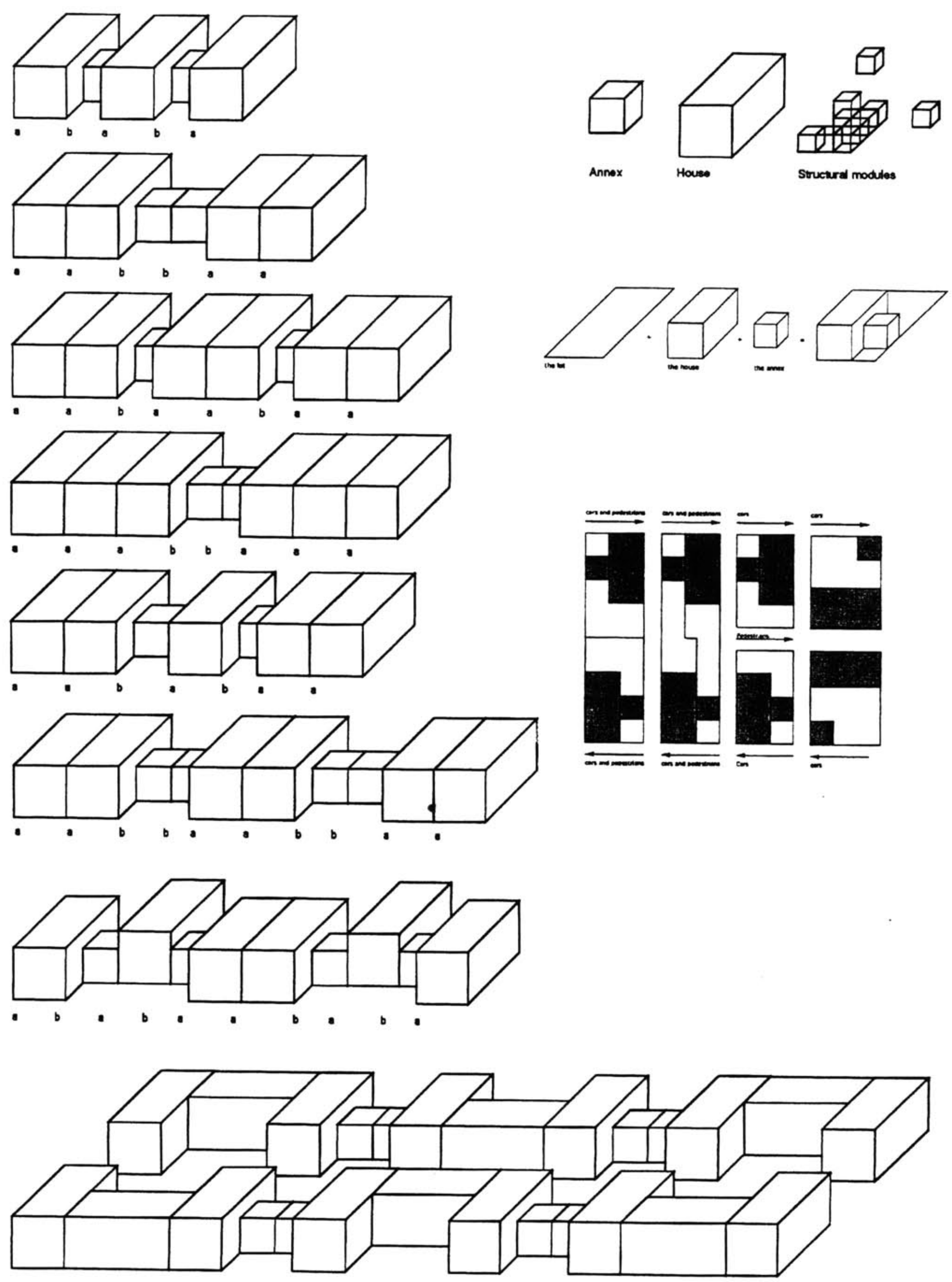
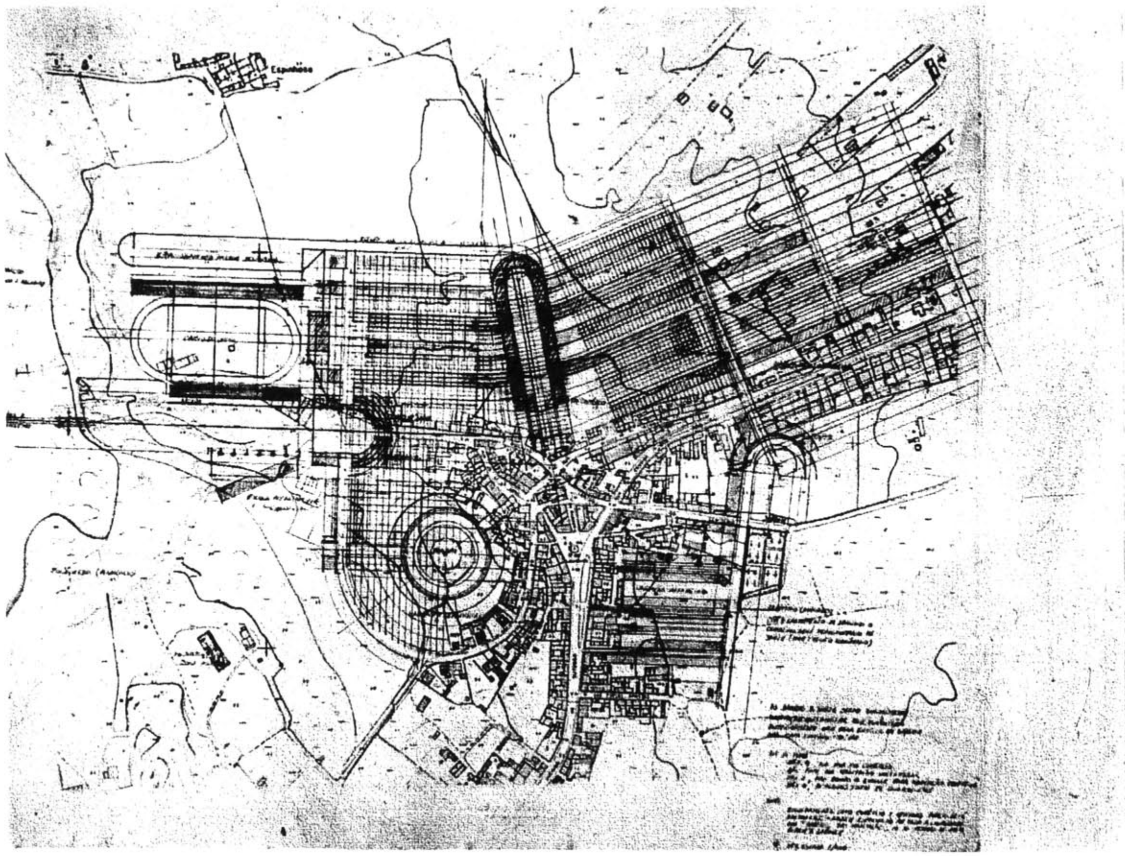
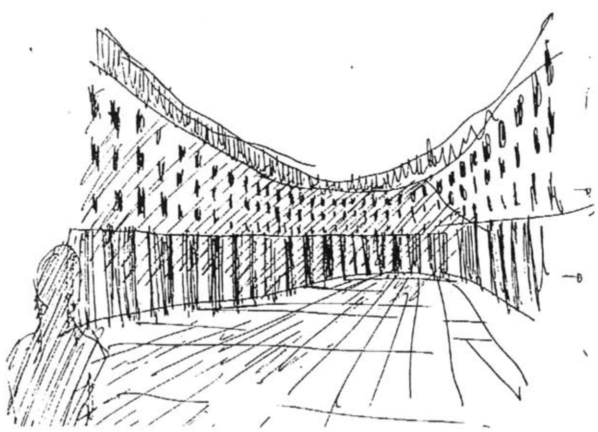


Fig. 2.18
The modular scale
From the building to the street:
by different associations of
single family buildings, we
obtain different streets blocks,
and different urban patterns





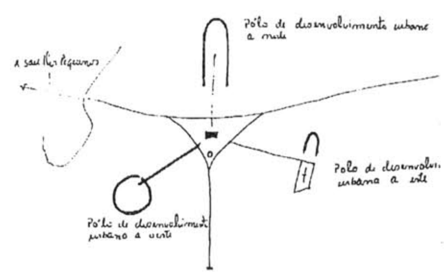


Fig. 2.19
The modular scale
From the block to the neighborhood: by combining the different blocks, we obtain different neighborhoods, and then a town

2.2.6 Controlling mechanism

The *control mechanism* assumes four *control factors*: the degree of repetition, the degree of diversity, the degree of variables freezing, and the degree of prefabrication. These four factors, mutually dependent, guarantee architectural unity and the control of costs.

The interaction between the controlling factors follows specific principles. A high degree of prefabrication, requires a high degree of repetition. A high degree of repetition rationalizes construction and reduces the cost. It also increases architectural unity and order. Nevertheless, it requires a high degree of variables freezing, thus reducing the degree of diversity. The degree of diversity can, thus, be constrained by freezing variables for economic or for architectural reasons.

It can be frozen for economic reasons in order to guarantee the minimal degree of repetition required to meet a fixed cost, considering the scale of the design. This means that in order to control costs and achieve a scale economy, the number of different elements used in an architectural composition depends on the scale of that intervention; the number of different modules to be used in the design of a single house would be different from the number of different modules used in a five hundred dwelling development.

The degree of diversity can be frozen for architectural reasons when, in order to maintain unity and harmony, the values of certain variables are limited. This means that in order to guarantee unity, the number and location of different elements in an architectural composition have to be limited.

An effective use of the mechanism to control costs and diversity requires in turn the establishment of rules based on the principles that regulate the control factors. An example of a rule to control the cost could be: in this development, no more than five different windows can be used. An example of a rule to control architectural unity could be: in this street, the windows should be red or black.

2.2.7 - Evolution

Three basic types of evolution are possible. First, the structure and the outside limits of the building are fixed and evolution occurs due to changes in the partition wall system. Second, the outside limit can also change, increasing the space available, and the possibilities of evolution. Third, the structure can be expanded, increasing the possibilities of evolution. Figure 2.20 illustrates a combined evolution for a single family dwelling.

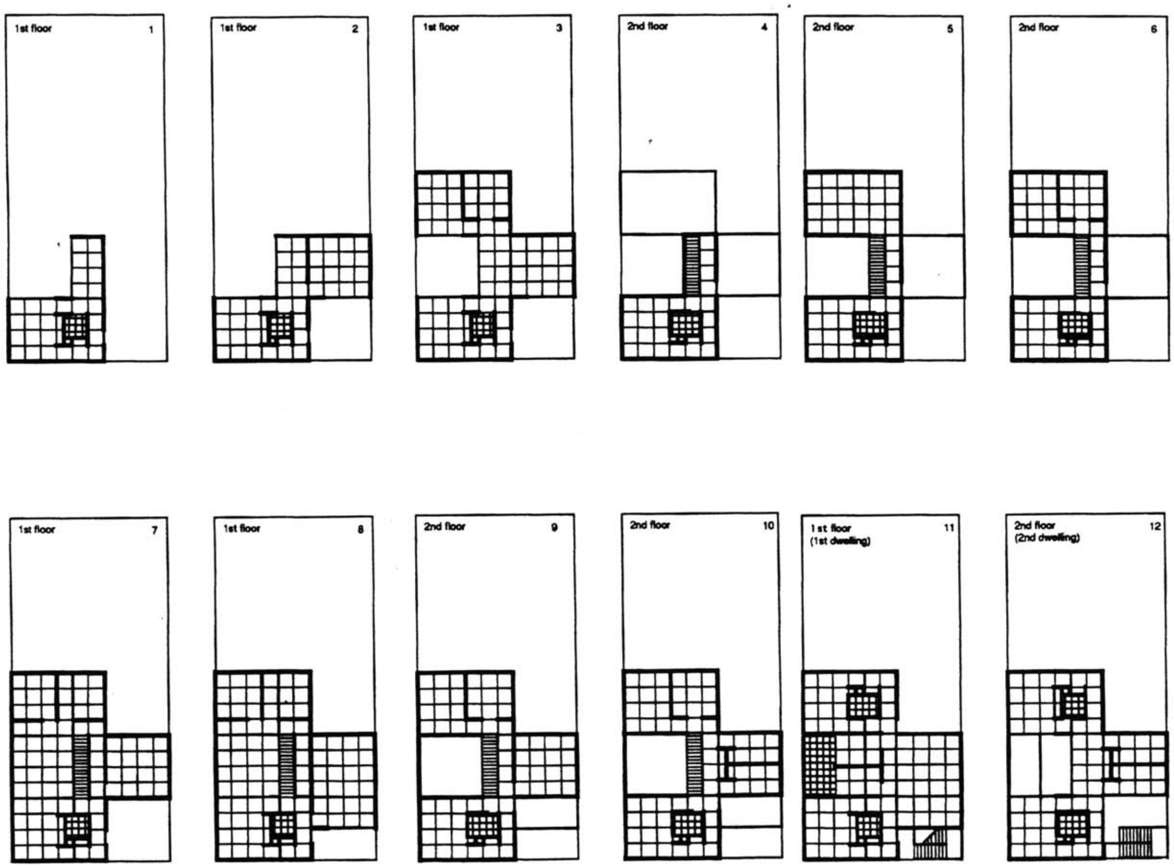


Fig. 2.20
Combined evolution of a dwelling into two dwellings

2.3 The problems of the solution

As seen in the previous section, the developed system possessed both generation capabilities and controlling mechanisms. However, in my design attempts using the system, I faced severe difficulties. On one hand, the high flexibility of the system made difficult to make decisions and progress in the design process. On another, once these hurdles were overcome, the results of my design, would not meet the expectations that had led me to develop the system. Namely, the amount of repetition was unacceptable (Fig. 2.21). This experience questioned the developed system and so in order to understand the origins of its limitation to generate diversity, a new research was undertaken. It proceeded through four steps.

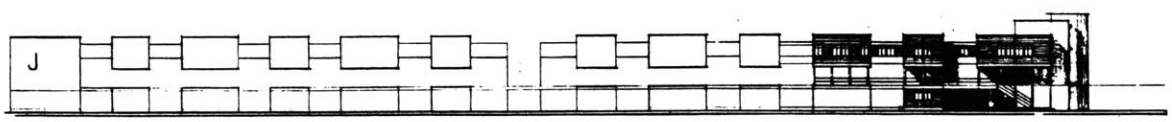


Fig. 2.21
Example of street facade conceived within the system in which diversity is lower than the desired

First, the designs generated within the developed system were carefully analyzed. It revealed the use of repeated patterns at different levels. For instance, although the system was able to generate dwellings with different configurations, and despite initial attempts to pursue this goal, as shown in early drawings, the final design had been used for only a few dwelling types.

Second, a non-planned and diverse settlement was carefully analyzed. The material studied included historical, geographical, social, and morphological analysis. The aim was to observe how the relationships among the inhabitants, and between them and the environment were reflected in the

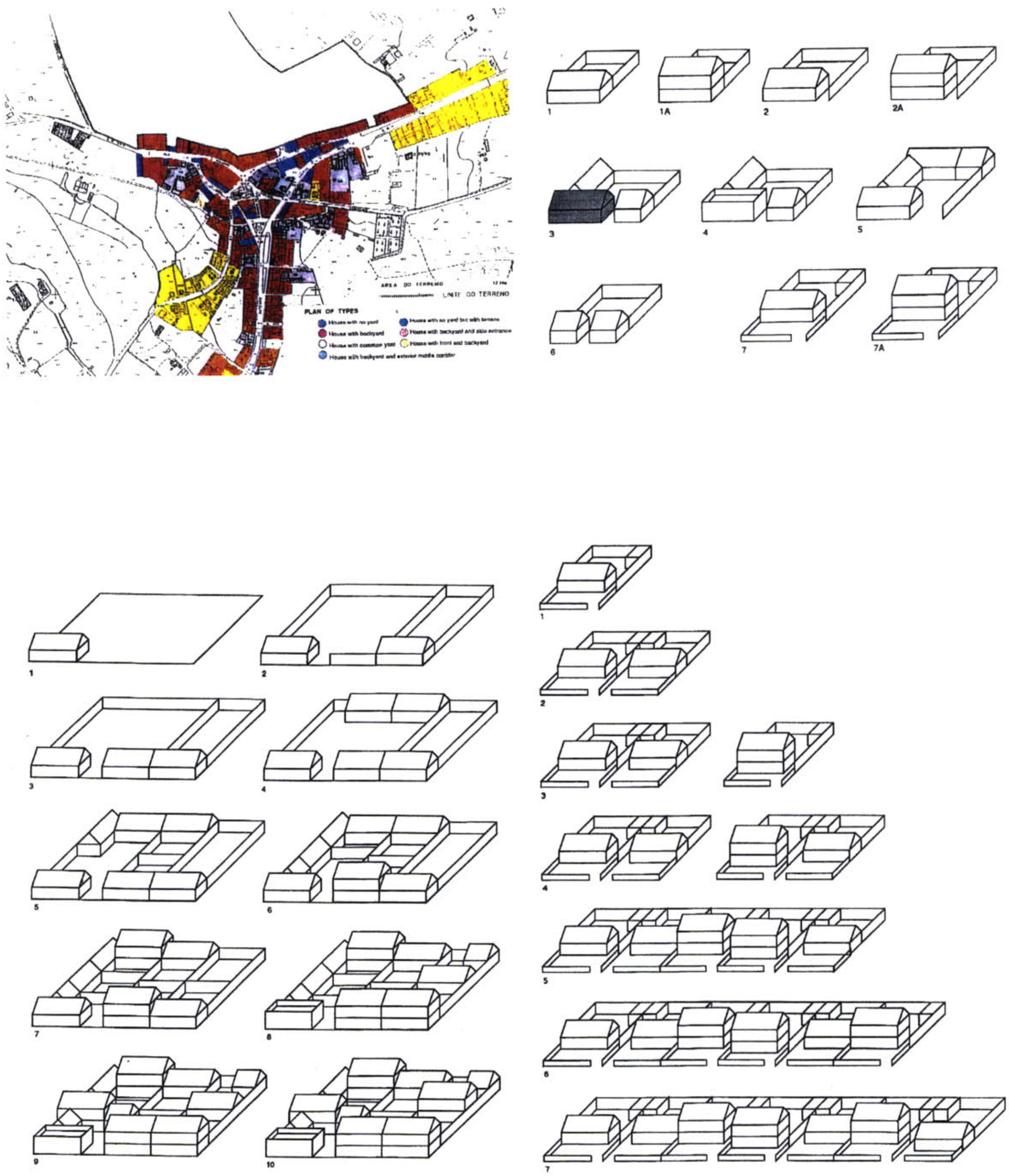


Fig. 2.22
Sarilhos Grandes, Portugal
Analysis of an informal settlement: plan, housing types, spontaneous growth through densification, and through expansion

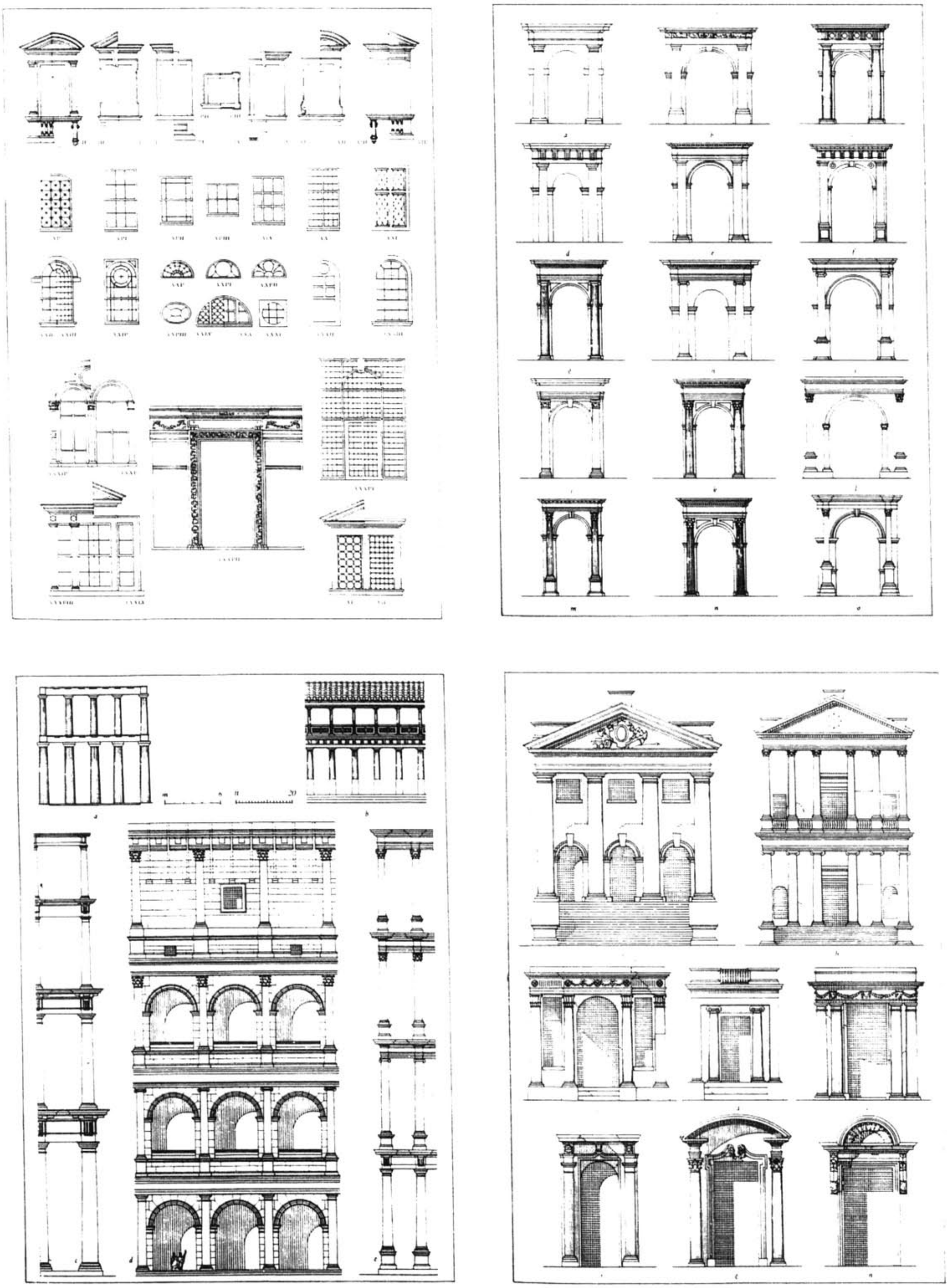


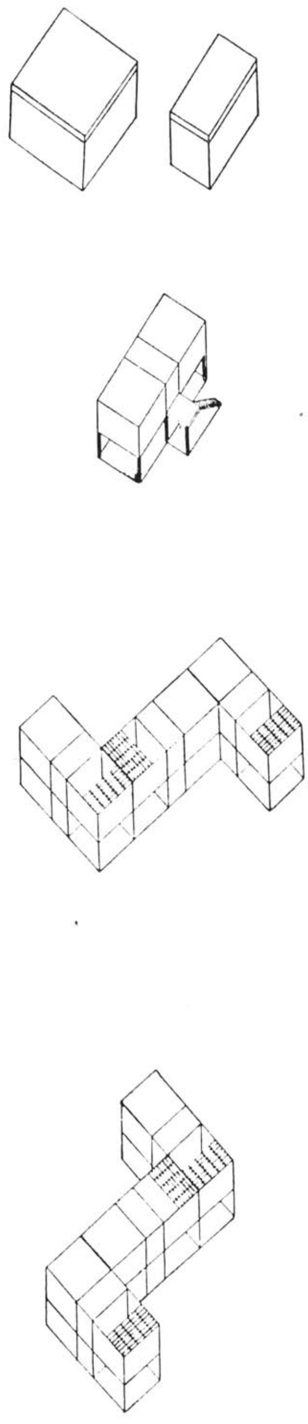
Fig. 2.23
The use of architectural modules has been a fact throughout history allowing the generation of diverse artifacts

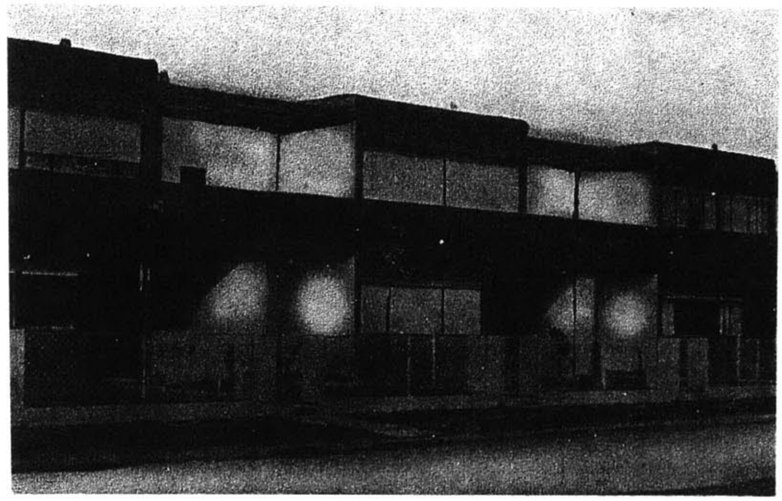
built environment, in order to understand how diversity had been achieved. So, I looked for patterns and I found them. First, concentrating on the map of a specific time, I identified some building types, and some variations within those types within the composition of the urban fabric. Second, comparing maps from different times, I detected that the process of urban growth was also based on these types, either through expansion or densification processes (Fig. 2.22).

Third, a historical analysis was done in order to track the presence of the concepts of type and module in architecture. Although cursorily, I confirmed the overwhelming presence of these two concepts in architecture, and their ability to generate diverse architectural artifacts (Fig. 2.23).

The fourth step was to make a deeper analysis of other approaches to the mass production of architecture. The selected approaches were suggested by historical survey to cast some light on the research. They were Le Corbusier's housing development at Pessac (Fig. 2.24), Habraken's theory of supports (Fig. 2.25), and Siza's development at Malagueira (Fig. 2.26). This analysis allowed a direct comparison between the different approaches and the developed modular system.

Le Corbusier's and Siza's projects shared some methodological principles, such as the use of building types as the primary module of composition, and the conception of a 'design game' to generate several variations within the same type. However, there was an important difference: while at Pessac the 'design game' was confined to a 'container', at Malagueira, the game implied additional 'permissible moves' outside the initial container. Habraken's approach was more abstract in the sense that it did not suggest specific layouts. However, the idea of an abstract type was present, for instance, in his suggestion of Alpha, Beta and Gama zones.





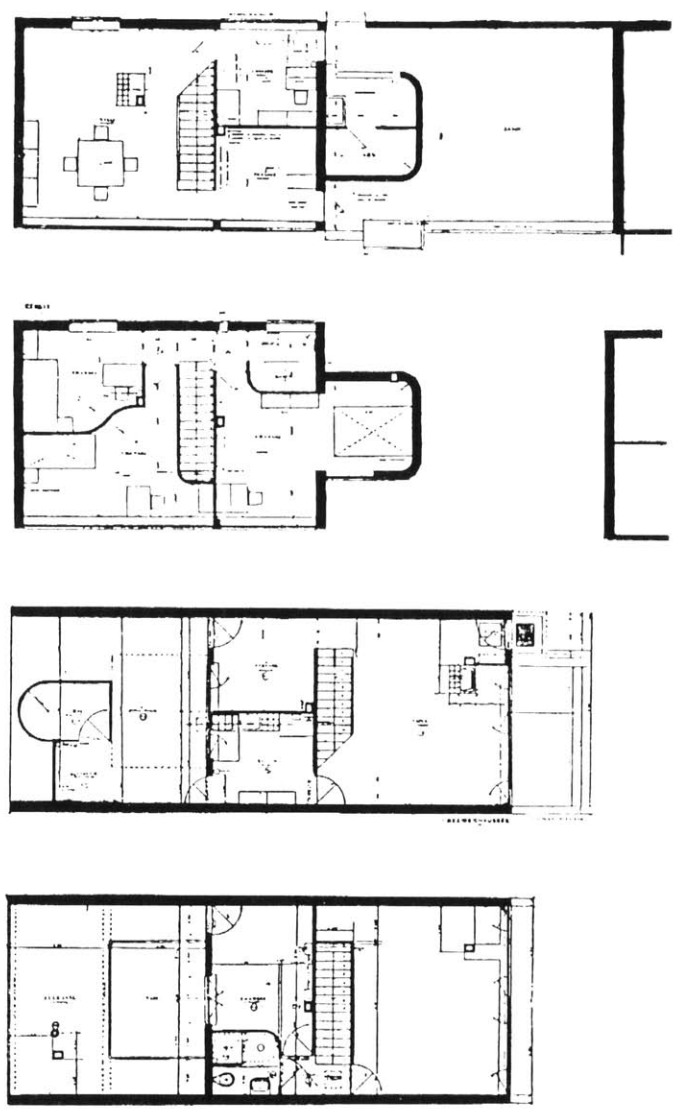


Fig. 2.24
Le Corbusier, 1927
Housing development at
Pessac, France

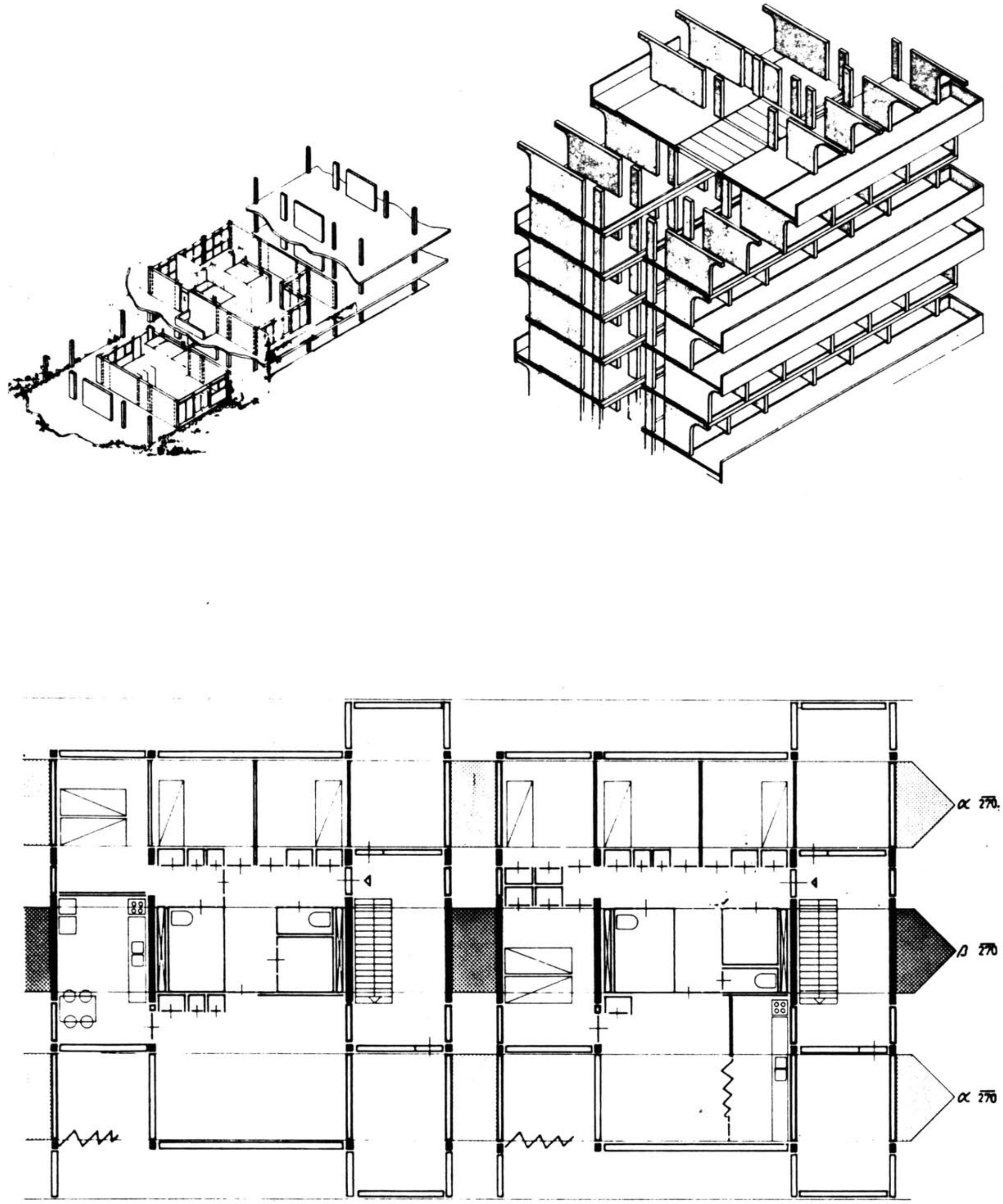


Fig. 2.25
N. J. Habraken, 1960s
Theory of supports

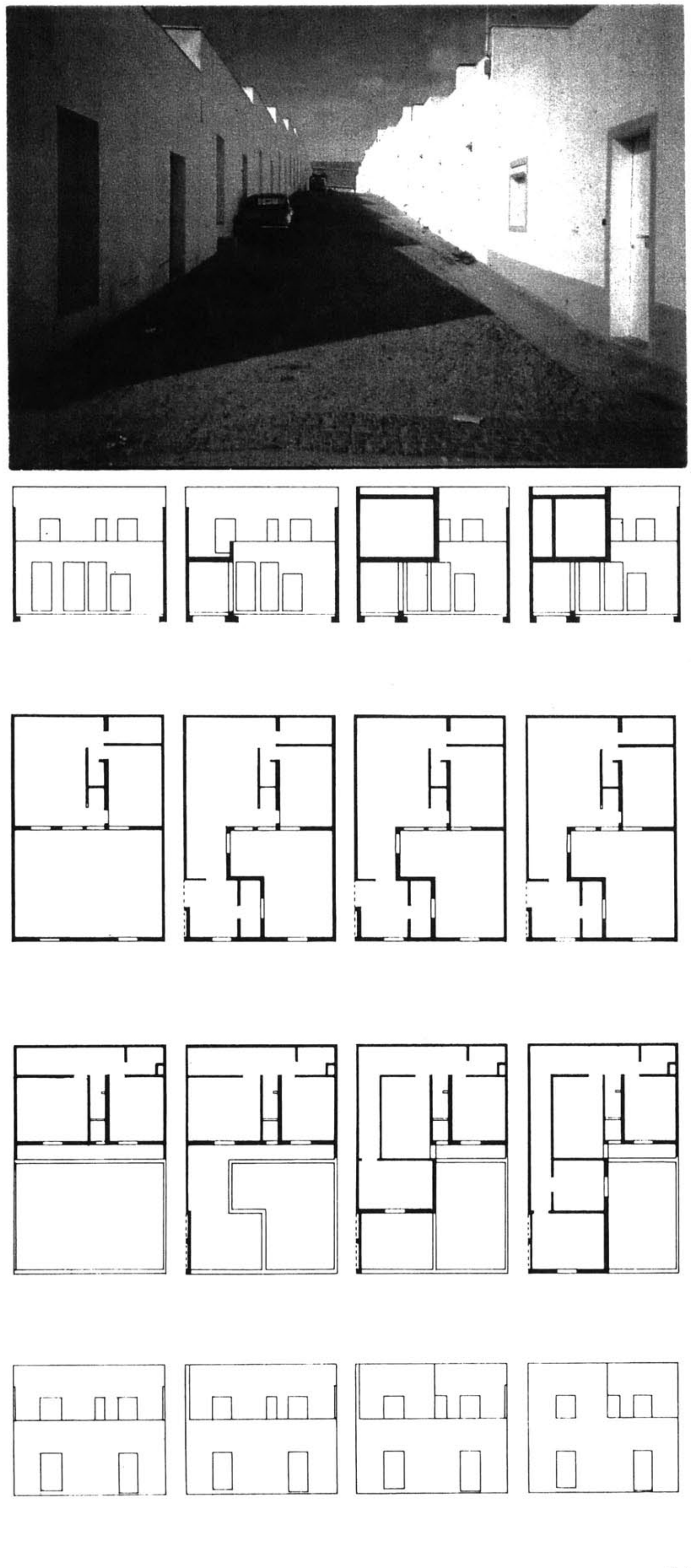


Fig. 2.26
Alvaro Siza, 1972
Housing development at
Malagueira, Portugal

The comparison of the developed system with those approaches revealed some similarities. The high level of abstraction of the developed system paralleled Habraken's theory, in their search for a methodology that would not tie designers to specific forms and in the use of rules to guide design. The developed system paralleled Le Corbusier's and Siza's approaches, in their concern for the conception of a specific design game. Among the dissimilarities between their works and the developed system is the greater concern for the conception of a building system to match the potential of the design system, the possibility of the deconstruction of a house by the user, and the introduction of a clearly defined controlling mechanism. Nevertheless, despite the similarities and dissimilarities among the approaches, advantages and disadvantages of one or another, there was a common flaw: the lack of architectural diversity.

The conclusion of this research was twofold. It concluded that the presence of modules was overwhelming in architecture, and that it was behind the diversity found in either non-planned settlements or in architectural artifacts produced at different points in time. It suggested, thus, that a modular system was a valid idea to rationalize the production of housing and produce diverse designs. The research also concluded that the specific use of modular systems with the goal to create diversity failed to do so.

3. The Problem

The problem can be stated as follows. Designers have been concerned with the development of design systems that would balance flexibility and diversity and provide a consistent framework for the systematic production of built artifacts. However, when we analyze what designers design with these systems, we realize that the outcome does not meet the purposes that led to the development of such systems. Namely, the amount of repetition is unacceptable. Additionally, the use of such systems by other designers, beyond the ones who develop them, is rather restricted.

Addressing the problem described above, two viewpoints can be taken. Either the problem is connected to the conception of these systems, or to the designers themselves. First, I explore the first viewpoint. I raise two hypotheses that could explain the design systems' failure and I address the issue of universality of design systems. Then, I concentrate on the second viewpoint. I propose an explanation for the designers failure to use modular systems in the generation of diversity, and I discuss whether the computer could be used to overcome this flaw. I thus prepare the ground for the presentation of a design experiment aimed at exploring the roots of the problem and discovering possible solutions.

From the perspective of a design systems' failure, I hypothesize that the problem has two different explanations: one is related to technological issues, and the other is related to cognitive aspects. The technological explanation derives from a close comparison between the theoretical goals of the designers and the physical behavior of the systems they created, as well as from my own effort to design a specific system. In fact, ideas that work well at a theoretical level are often technically difficult to implement. For instance, the interchangeability of modules requires the resolution of difficult geometrical problems, such as dimensional coordination, as well as the resolution of technical ones such as the joints between the modules. The cognitive explanation derived from the observation that even when technical problems are solved, designers still have trouble designing with those systems. Either it is possible to capture the way people design into a common framework, but those systems fail to capture it, or the way people design is so diverse that it cannot be captured into a common framework at all.

I believe that although the technological explanation is important and accurate at many levels, it cannot account for all the insufficiencies of these systems. Moreover, it is not the main issue. Therefore, the solution for the problem should be sought in the cognitive realm before any technological problem is addressed. This study is thus directed towards a cognitive explanation of the lack of architectural diversity in the mass-production of housing.

However, this stand point raises an important research issue. Should the problem of architectural production be re-stated, or should we insist on seeking an answer within the framework developed? This dilemma raises another important question that requires a reevaluation of goals. Is the concern the mass-production of architecture, or is the concern the production of architecture in general? How are they different? If the concern is the production of architecture in general, then we are searching for some kind of universal system. The impact of such an acknowledgment could not be greater.

In my research, by no means had I ever thought that I was developing a universal system. Yet, I was aiming for some sort of universality. I suggest that different specific systems could be developed for specific contexts, and that designers could either develop their own system, or work with a system to which they were sympathetic. Therefore, even the idea of a system provided means to solve a given problem in a given context. In this sense, it was appropriate and non-universal. Nevertheless, since it implied rules to define a specific system, it also implied that a way to encode general architectural knowledge would have to be possible. In this sense it implied universality.

How do the other systems analyzed face the problem of universality? It is true that those systems in general aim at embedding some sort of universal knowledge when they pre-solve some problems in a systematic way, such as by using dimensional coordination. It is also true that when they pre-define a solution, they are restricting the universe of possible solutions, and therefore they are not universal. Consequently, the more abstract these systems, the greater their degree of universality is; Habraken' s theory is more universal than either Le Corbusier's or Siza's approaches.

What would a system have to do to be considered universal? It would have to make possible the solution to any kind of problem in all possible ways. What entity would be able to manipulate such a system? It is evident that a human designer would not be able to do it. A human designer cannot solve an architectural problem the same way another does, because they have different reasoning skills and different cultural backgrounds. We must reframe our concern for universality. We happen to be interested in universality only to the extent that we are interested in diversity. So, if a designer cannot solve a design problem the same way another does, he will never use a modular system in the way as another designer does: so he will never be able to use the entire potential of such a system to generate diversity. Therefore, we have to conclude that the failure to generate diversity is more a fault of the designer.

There is another factor that supports the idea that human designers have a limited ability to use a modular system to generate diversity—their inability to manipulate simultaneously many pieces of data. This idea is described by William Mitchell who says that:

> *It is recognized that the human brain, superb computer that it is in many ways, is incapable of solving or keeping track of more than just a few simultaneously reacting factors at a time, and that mathematical tools must be relied upon to handle multifaceted problems. (Mitchell 1986)*

The possibility of using the computer requires one to address three problems: 'naturalness,' the role of the computer, and what would be necessary to automate design.

The first issue, "naturalness," is an inner question in the assessment of design systems. Its absence might well rest behind their failure:

> *Although design is basically a 'human' process by definition, it is necessary to differentiate it from machine-design, or computer aided design, and design methods, or rational design-tools for human designers. (...) In the past, the biggest road block for the wide-spread of design tools in the architectural offices has been the incompatibility of these non-intuitive tools with those of intuitive design." (Akin, p.23)*

So, there is a difference between natural design and rational design. There are only two positions facing the dichotomy natural/rational: we must either refuse or accept this incompatibility. If we refuse it we need to find another model that corresponds to the way people naturally design. If we accept the incompatibility, we can accept the non-naturalness of rational systems and use them, nevertheless, to develop an artificial way of designing.

The second issue, is philosophical in nature. What do we want the computer for? There are various options. They range from using the computer as a simple library of design modules, with no knowledge about how to combine them, to fully automated design, eleminating the human designer. If we want to fully automate design is it not contradictory to wish the development of machines that do what people cannot do and yet expect them to behave like people, at the same time? Therefore, if we are concerned with automated design, "naturalness" might not be an issue.

What would be necessary then to automate design within a particular modular system? Use of the computer would require at least three different basic programs. First, it would require a program containing the information about the system, such as the number and features of its modules, or the possible arrangements between them. Second, it would require a program containing the information about the site, and third, it would require a program with the user requirements. And, of course a mechanism to link the three. Only then, would design be automated.

However, even if we are successful in our attempt to transform the computer into a skillful designer knowing how to use a modular system we could not guarantee that the computer would know how to generate diverse designs. First, we have to ensure that human designers know how to do it because, if they do not, we have to find a new paradigm. Second, in all cases, we have to infer the rules to achieve diversity. Finally, we have to instruct the computer of these rules. Thereby ensuring that the computer would generate diverse designs.

In conclusion, I devised an experiment which is primarily concerned with the issue of diversity. It attempts to discover to what extent the problem was due to an inefficiency of design systems or to an inability of designers, and if designers are responsible, why they fail to achieve diversity. Finally, what are the rules that govern diversity.

4. The Hypotheses

In order to explain why designers fail to use a modular system to generate diversity, I raise six different but related hypotheses.

The first hypothesis states that a designer's failure to generate diversity is due to his/her sense of order. This sense can either be connected to the structure of human mind, embedded order, or to our education, that is, acquired order. In this latter case it is important to distinguish between order acquired by general education, and order acquired by architectural education. How much is a designer's 'inability' to deal with diversity due to each of these kinds of orders? I believe that current architectural education and design theory mirrors our tendency towards order and reinforces it.

The second hypothesis indicates memory limitations behind the failure to generate diversity. This hypothesis is also related to the structure of human mind, and it can be described as a limited ability to deal with great amounts of varying data.

The third hypothesis says that the difficulty to generate diversity is due to our need to operate with constraints. This need is mirrored in a designer's tendency to constrain the context in which the design evolves when it was not constrained at the beginning. It is important to distinguished between constraints that we impose on ourselves, voluntary constraints, and constraints that are dictated by our internal order, non-voluntary constraints. The first kind of constraint is connected to the issue of memory, while the non-voluntary is connected to the issue of order.

The fourth hypothesis indicates time as the factor responsible for the lack of diversity. Since the generation of diversity requires designers to manipulation of more data than uniformity does, it is more time-consuming. The importance of time is emphasized by the conditions under which designs evolve in architectural firms. These firms are often limited by deadlines and economical constraints that prevent an effective exploration during the design process.

The fifth hypotheses states that a designer's failure to generate diversity is due to his/her tendency to treat design artifacts as a whole, no matter their real scales. This tendency can be either due to current architectural trends and education, or to the way design artifacts are represented during the design process. When we are designing a group of buildings, for instance, and we have to represent them on a certain sized sheet of paper, it is difficult to establish differences in details, and so we might tend to limit diversity.

Finally, the sixth hypothesis states that the lack of diversity is caused by the lack of a design theory that successfully addresses the issue. This flaw can be explained by historical factors. The systematic need for large scale developments in which the lack of diversity is more perceivable, emerged only after the industrial revolution, a mere two hundred years ago. We have thus been confronted with the lack of architectural diversity for a period not long enough to permit the emergence of such a theory. It is assumed, therefore, that existing design theory and its concerns for symmetry, proportion, and rhythm, does not tell us how to generate diversity in such large developments.

5. The Experiment

Two different experiments—Experiment A and Experiment B—were devised and then one experiment A, and several Experiments B were done. Experiment A, tried to simulate a situation in which a designer has to solve a design problem and achieve diversity, using abstract shapes. I called this experiment *The Spoken Game with Abstract Elements*. Experiment B tried to simulate a similar situation, but instead, using shapes that represented elements of the modular system presented in Section 2, thus the name *The Spoken Game with Architectural Elements*. Both experiments constituted protocol analysis studies as defined by Akin:

> *Protocol analysis is a technique devised to infer the information processing mechanisms underlying human problem solving behavior. A protocol is the recorded behavior of the problem solver..(Akin, p. 24)*

In both experiments, the recorded speeches of the designers while designing, and the recorded drawings of the evolving design constituted the protocol.

5.1 Precedents

The experiments devised were partially inspired by two other experiments: the *Silent Game (Schon, Porter, Ackerman)* and the *Disposable Metaphor (Fargas and Papazian)*. The 'Silent Game' is an experiment that has been undertaken in the Design Research Seminar at MIT for some time. This experiment requires two builders, Builder A and Builder B, and Lego blocks.

> *Builder A has to build something out of the Lego blocks following implicit rules, in such a way that Builder B can follow the rules. Builder B continues building according to what he thinks the rules are. The two builders are not allowed to speak. After each of B's designs, Builder A informs Builder B about the deviation of his design from the rule he had used, using a code of Lego wheels. (From class notes)*

As a variation of the Silent Game, my experiments retain the idea of using two designers. However, there are three changes. First, both types of experiments used the computer as the design media instead of Lego blocks. Therefore, the modules were shapes on the computer screen. The goal was to place the experiments closer to a design environment, rather than to a building one. Second, the designers were asked to express their thoughts aloud —thus the name Spoken *Game*—in order to gather more spontaneous responses. Third, in Experiment B, the shapes used in the design had an architectural meaning, and the designer was assigned a specific architectural task. The goal was to bring the experiments into an architectural context.

The *Disposable Metaphors* was an experiment conducted for the first time by Fargas and Papazian in the Design Research Seminar two years ago.

> *In [this] experiment, designers were shown, on a computer screen, randomly generated pictures consisting of a frame, two lines and two rectangles. The design task was to make the picture more "stable". The computer would record the designer's moves, and later produce a real-time replay or a dynamic record of the process. (Papazian, p. 15)*

From the Disposable Metaphors, Experiment B continued the idea of using a computer program to trace design process. Nevertheless, the process of tracing was different. Instead, a computer program called Design Tracer which I developed was used.

5.2 The Setting

Experiment A used two subjects, subject A and subject B, who remained in separate rooms, working at two different computers. A network connected the two computers, and a software called Timbuktu allowed the simultaneous display of the same window on the two computers. No computer program traced the design process. This setting is diagrammed in Fig. 5.1. In Experiment B, this setting was abandoned because a test

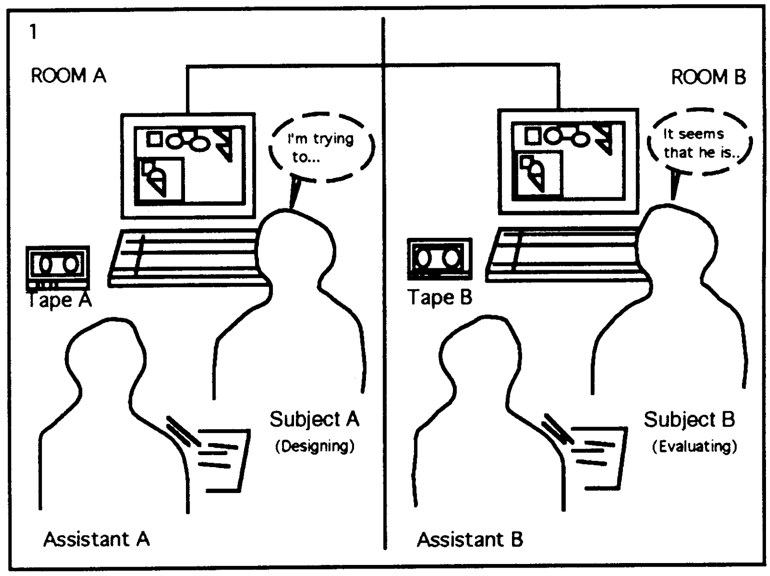


Fig. 5.1
The setting of the first experiment: The Spoken Game with Abstract Elements

revealed that when Timbuktu and the Design Tracer were running at the same time, the computer slowed down so much that the experiment became inefficient. Experiment B had, thus, two variations. In the first, the experiment used only one subject whereas in the second one, it used two subjects as in Experiment A. Once Subject A finished his design he was asked to leave the room. Then, Subject B was shown a printed copy of A's design, and asked to reply to A's design following the same rule. The reason for insisting in using two subjects was the belief that their presence would reveal the rules used by subject A in

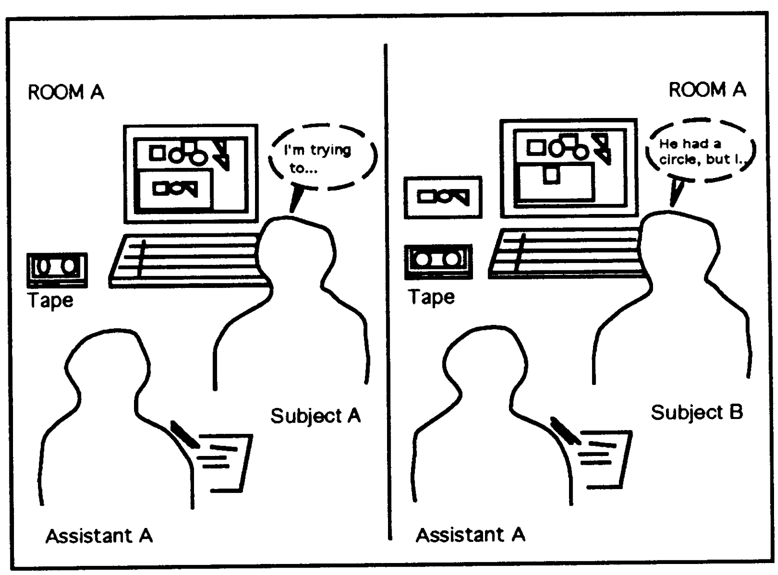


Fig. 5.2
The setting of the second type of experiments: *The Spoken Game with Architectural Elements*

his design as well as B's perception of the diversity of A's design. This setting is diagrammed in Fig. 5.2.

5.3 The Task

In Experiment A, the design task assigned to the designers was to create a composition out of abstract shapes that went from the left to the right and was diverse. The 'drawing board' of this experiment is shown in Fig. 5.3. However, the results of the experiment revealed that the abstract shapes allowed too much choice and, therefore, made difficult to discuss diversity within the context of architecture beyond a certain point. Therefore, Experiments B was devised.

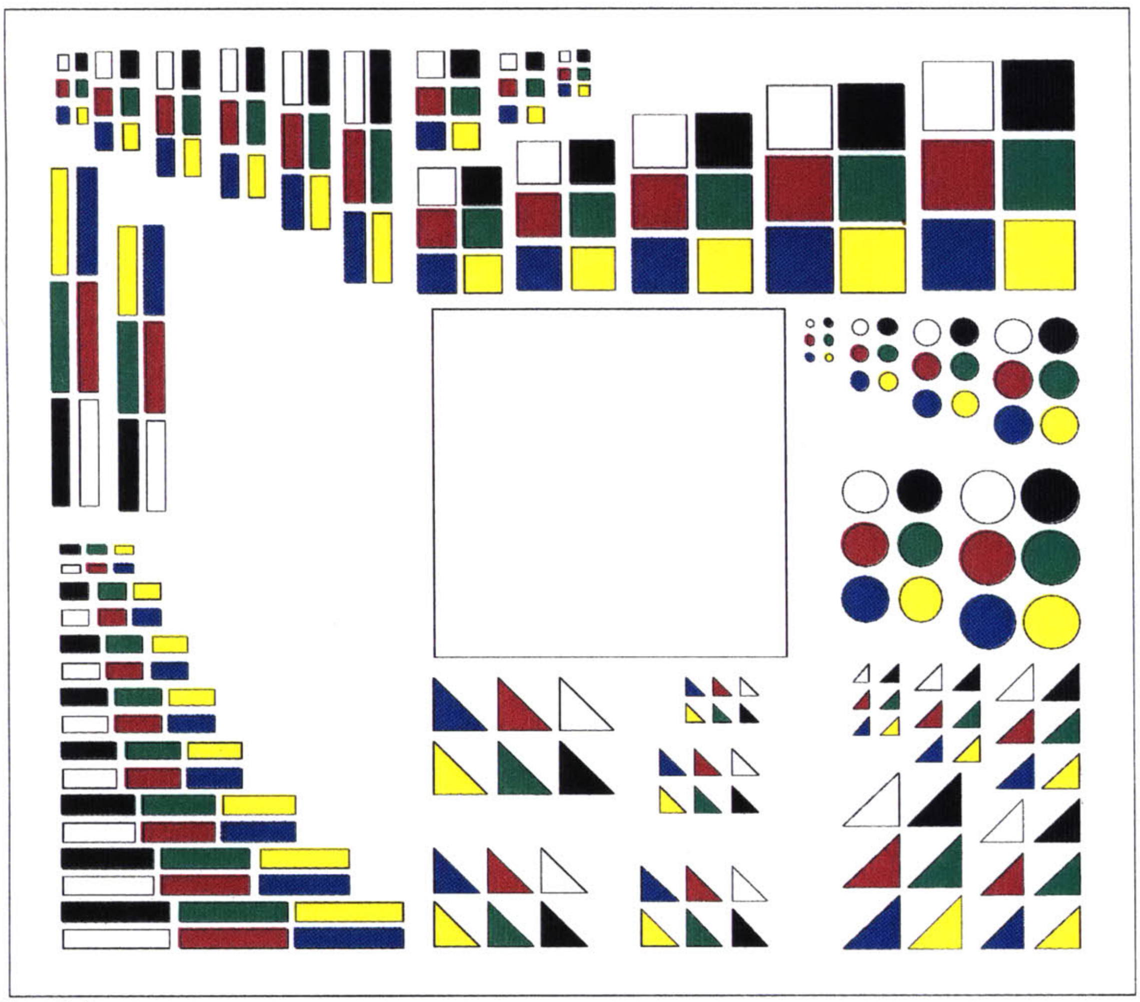


Fig. 5.3
The drawing board of *The Spoken Game with Abstract Elements*

In Experiment A, the task was to *design facades out of the elements provided and make them diverse.* It is a two-dimensional design, where the components of the design/building system, such as, structural elements, wall panels, and windows are represented by shapes. The use of appropriate colors and hatch patterns were an attempt to give an idea of what the materials of those elements were. The final drawing board of the experiment is illustrated in Fig. 5.4. The selection of facades as the objective of the design task was due to the consideration that the lack of diversity in a urban environment is more perceptible at the street level.

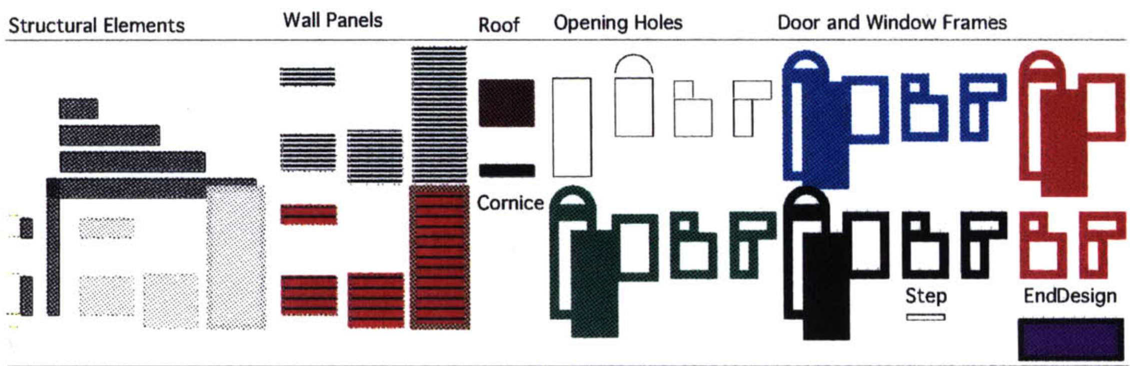


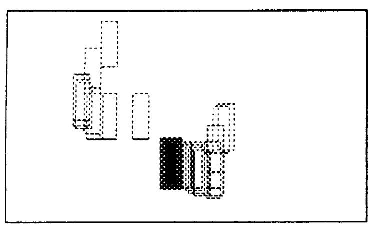
Fig. 5.4
The drawing board of *The Spoken Game with Architectural Elements*

5.4 Permissible Moves

The only design moves allowed in both experiments were the selection of an element, the transportation of that element to the chosen place, the re-selection and transportation of an element previously selected to a new place or its rejection (temporarily or permanent) from the design. Before each experiment started, the subjects were shown how the building system and the Design Tracer worked, by using a small design.

5.5 Profile of the subjects

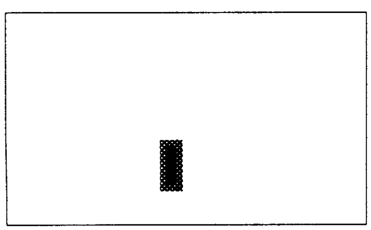
The two subjects in Experiment A were graduate students of architecture with a bachelor's degree in the field, whose design work was considered top in their studios. Two out of the eight subjects in Experiment B were not design students but graduate students from other areas. The goal was to determine whether architectural education constrained designers ability to create diversity.



The display of the Move Trace Layer: the move

5.6 Computer Environment

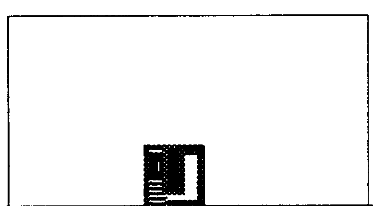
The computer environment consisted of a Macintosh computers as the hardware and MiniCad as the CAD system.



The display of the Move Layer: the result of the move

5.7 Protocol and storing process

The protocol included the tape recorded speech of the designers in both experiments, and also the recorded drawings of the evolving design process in Experiment B. The drawings were recorded by the Design Tracer which was written in MiniPascal, the embedded programming language in MiniCad. The way the information is stored by the Design Tracer is illustrated in Fig. 5.5. The program stored each move into different layers and a careful selection of layers once the design finished made it possible to retrieve the state of the design after a certain move or series of moves.



The display of the Board Layer: the design after the move

Fig. 5.5
The storage process of the design moves by the Design tracer

6. The Results

The experimental results are the graphic and verbal protocols gathered during both experiments, and by the analyses of these protocols. The complete results are shown in appendixes at the end of this study. I would like, nevertheless, to comment briefly about the retrieval and the analysis processes of both protocols.

The Graphic Protocol of the 'Spoken Game with Abstract Elements' is not only a designer's the final designs, saved after the subject finished his/her designs, but also all the intermediate stages of their design process. These intermediate design stages were either saved during the design processes, using the normal Macintosh *Save* command, or reconstituted using the information provided by the Verbal Protocol. The results obtained were then printed, and are shown in Appendix A.1. The Verbal Protocol is all the portions of speech transferred from the tape-records into a written form and is shown in Appendix A.2. The analyses of both protocols were summarized either in the form of graphics or tables. The graphics are shown in Appendix A.3, and the tables in Appendix A.4.

The graphic protocol of the 'Spoken Game with Architectural Elements' is all the design stages of the different design processes, and retrieved in a two-step process. First, we retrieved all the design stages after a sequence of five or ten moves, depending on how much the design had evolved after each sequence of moves. The different design stages were then organized into chronological order like in a cartoon. These cartoons were analyzed, and then a second retrieval process took place, according to a more informative criterion. In this second retrieval process, we considered only the design stages achieved after a sequence of moves that represented a certain design intention, such as the construction of a structural bay . The different design stages obtained were then organized again into a cartoon form. The results of this retrieval process are shown in Appendix B.1. The retrieval of the verbal protocol followed the same process of Experiment A, and the results are shown in Appendix B.2. The analyses of both protocols are shown in Appendix B.3 (graphics) and in Appendix B.4 (tables).

7. The Discussion

7.1 'The Spoken Game with Abstract Elements' (Experiment A)

This experiment had two goals behind it. First, it aimed at testing the validity of some of the hypothesis I raised to explain why designers fail to achieve diversity. Second, it aimed at finding the rule, or the rules, used by the two designers who participated in the experiment in their design and evaluation processes. If considering design a process that incorporates two interrelated activities, generation and evaluation (Mitchell, 1990), at least two different kinds of rules had to be involved: rules for generation and rules for evaluation. The experiment should help to externalize these rules and the relationship between them. Namely, it should clarify not only what the rules were, but also the difference between the generation and the evaluation rules. Both the experiment and these issues are diagrammed in Tables A.I. and A.II (Appendix A). Thomas was designer A, and Dan was designer B.

The generation rule used by designers is not the most *direct* due to memory and appraisal constraints

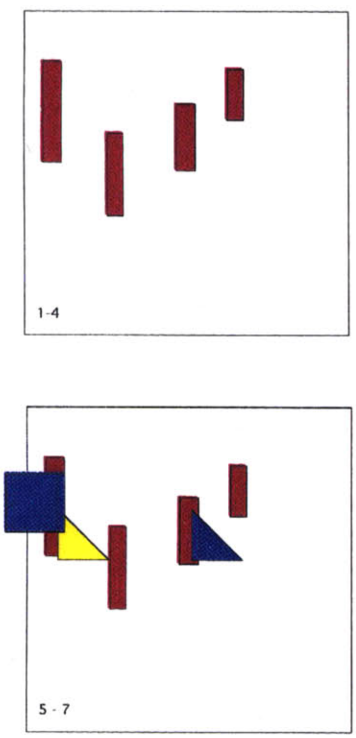
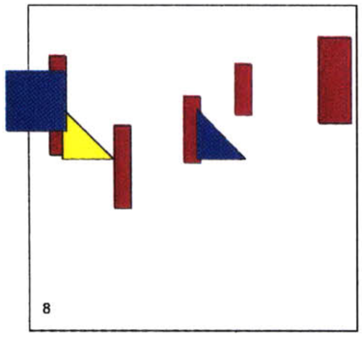


Fig. 7.1
Thomas' design process (moves 1 through 7)

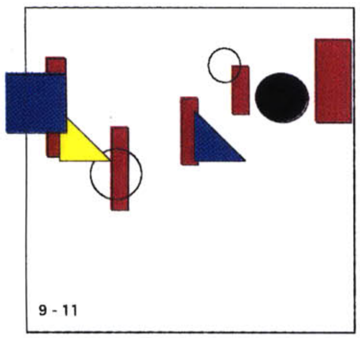
7.1.1 Memory and Appraisal

The generation rules the designers used to reach their design goals in their design processes during the experiment, were not the most direct. Nevertheless, they had a clear interpretation of the problem they were assigned, and a clear idea about what the goal was. On the other hand, Dan's design process was more direct than Thomas' because he was able to learn from watching Thomas designing, but also because he could look at Thomas' final design when he was designing. These arguments might seem trivial because one has no difficulty in confirming their veracity intuitively. Nevertheless, they are crucial, since they reveal the important role of memory and appraisal in the design process.

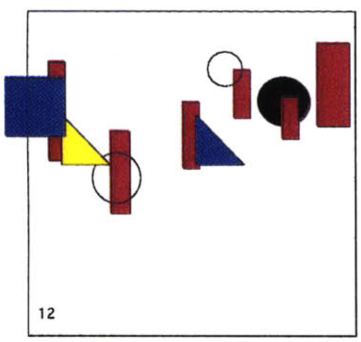


Both the verbal and the graphic protocol support the arguments. By analyzing Thomas' verbal protocol, one notices that he had a clear idea about the answer to the problem, and how to get there right from the beginning:

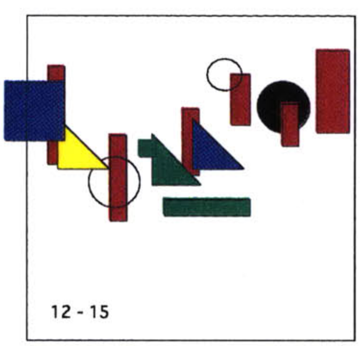
> *T: First I am going to repeat those vertical things in that direction. (...) (then) some smaller elements. All for the sake of diversity. Small elements of another color and size.*



In spite of the simplicity of the task however, he interrupted the placement of the red elements to place some smaller shapes and then fill them in with other shapes, instead of laying down the vertical elements all at once, as he had said, (Fig. 1). Therefore, he was not as direct as he said.



I raise two explanations for this fact: First, Thomas needed to lay down the elements of his idea before he forgot them. The 'memory space' needed to allocate the data required placing all the red elements required to empty that space from his ideas about the secondary elements. This suggests that the 'immediate memory'[1] that designers have available is limited. Second, when Thomas built a small part of the whole, he had the opportunity of evaluating the validity of his idea without having to wait until the entire design was finished. This way, he was able to test the solution at an early stage of the design process and make any eventual correction. This point, I believe, also relates to memory limitations. Because designers do not have the ability to record all the information about a certain stage of the design process, they need to keep these records in any format that enables them to asses the correspondent design stage at any time. This reasoning is supported by Dan's design . Dan had also a clear idea about the solution:



[1] I am assuming that humans have a short-term and a long term memory

Moreover, his design process was more direct than Thomas' (compare Figs. 1 and 2). Through watching Thomas designing, he saw the design evolving, and was able to match the process with the final result and cut it down to the essential steps. When he finally had to design he therefore eliminated unnecessary steps. Nevertheless, he also interrupted the placement of the red elements, the framework--as he called it later--to place the big blue square (Move 4, Fig. 7.2) that he considered highly meaningful:

> *D: (..)I broke up using the framework (the red elements) for that blue square because I saw it as significant'*

Therefore, his procedure was not the most efficient either, even taking as a reference his own description of Thomas' solution. This fact also supports the importance of memory in the design process. Because Dan saw the big blue square as significant, he decided he would use it in his design. Therefore, once he decided this, placing it in the drawing would empty his memory from the need to make that move, and it would enable him to asses its validity as well.

The dialogue Dan and I had, when I asked him toreply to Thomas' design, also supports the idea that memory and appraisal have a significant role in the way design process evolves. In fact, the dialogue is even more explicit in that respect. When Dan saw that I was about to take Thomas' design from the screen he reacted:

> *D: So, am I going to loose his (design) entirely?*
>
> *J: No, what I will try to is: do a new one .Copy this one, and...*
>
> *D: But I won't be able to see it as I am working?(..) Can I have a new (copy of Thomas')board? Without a new (copy of Thomas') board I can't react to what he had, except from my memory of it.*

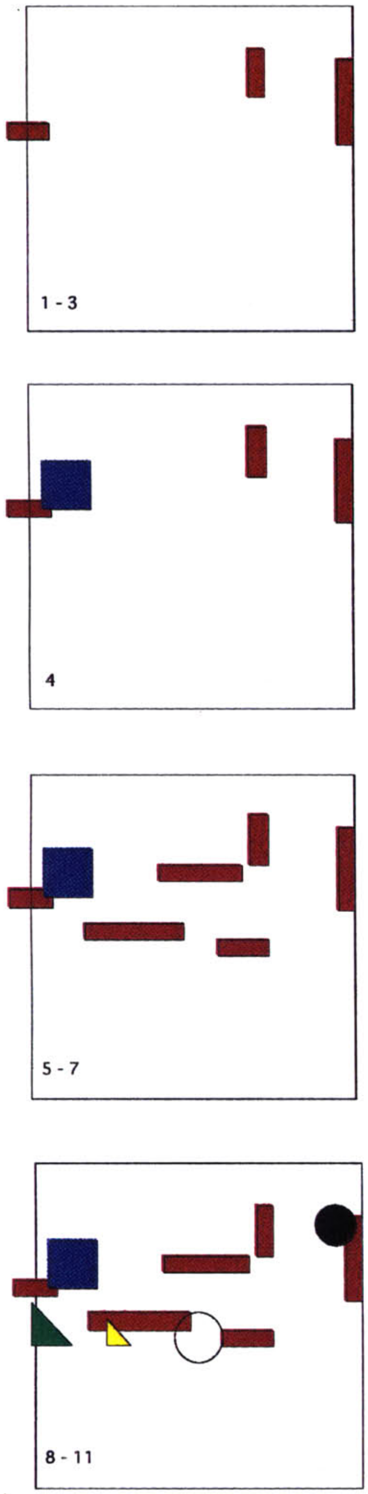


Fig. 7.2
Dan's design process

By removing Thomas' design from the screen, I was forcing Dan to use an important part of his memory to keep a picture of Thomas' design present in his mind. I was preventing Dan from having an easy reference he could look at any time in order to remind him of significant features, or just to compare with his design.

In summary, Thomas' and Dan's design processes were more convuluted than optimal search. This suggests that the rules designers use in their design process are not the most efficcient that one can think of. Memory and appraisal are important factors affecting this process.

One could question the notion of *efficiency* I employ here. By efficient, I mean the easiest imaginable way to solve a problem. If the problem were the connection of two points, it would be a straitght line. Nevertheless, as Einstein pointed out (Einstein, 19**), the easiest way and therefore the most efficient, to connect two points , is sometimes not a straight line. For instance, the easiest way to connect two points located on the surface of the Earth is a curved line. A straight line would require the consumption of more energy and take more time. When I say that the process that designers use is not the most efficient, I mean that it would not be a straight line if we represented the problem in the frame provided by Einstein's sample. Nevertheless, one can argue that it is the most efficient possible process. In some sense, this is what I am trying to point out: due to our memory limitations the most efficient possible process is not the most efficient imaginable process. Therefore, the most efficient design process depends on the conditions of the design. For instance, it might depend on *who* or *what* is designing.

7.1.2 Design Rules

The evaluation rules are more direct than the generation rules

Dan and Thomas used different design rules in their designs. Thomas' design rule had been to place the red elements from the left to the right, and to ocasionally interrupt this procedure in order to start laying down the secondary elements, and then continue placing the red elements from the left to the right, with the exception of the last one. This last red element was placed between two other red elements and on the top of a round black one (Fig. 7.1, move 12). This was possibly, to strengthen his idea of a 'wavy movement', but also because the distance between the existing red elements was too big, making the black element look like an exception among the other secondary elements.

Dan's design rule was: first, to 'frame' the composition by laying down the elements on the extremes, then to place the red elements, 'the frame', from the right to the left, and finally to place the secondary elements, 'the intuitive moves' (Fig. 7.2).

Therefore, Dan's design rule was different from Thomas design rule, which suggests, I would argue, that different designers might use different design rules to solve the same problem.

7.1.3 Evaluation Rules

The evaluation rules are more direct than the generation rules

The experiment also revealed a meaningful difference between evaluation and generation rules. When Dan interrupted the placement of the red elements to place the big blue square Thomas got confused :

> *T: See, what he does, either he hasn't understood it, which is possible, but I don't think so, or he just works in a different way, he doesn't set up this kind of... He doesn't work*

as methodological (?)[2] I think he has a compositional idea. He is balancing this thing while he is going.

He did not acknowledge that he had not followed the most efficient procedure either. Therefore, the rule he used to evaluate B's design was different from his own design rule, and it was also different from B's design rule. Moreover, his evaluation rule was more efficient than both Dan's and his own design rules. If one recalls how Thomas described how he was going to solve the design problem, one might go further and state that both of his own evaluation rules were more efficient than his and Dan's design rules. The statement is valid for Dan's evaluation rule of Thomas' design. One can now give a different aspect to Table A.I (Table A.II).

7.1.4 The Need To Freeze Variables

Designers need to freeze variables during the design and evaluation processes due to memory constraints

Thomas' and Dan's design and evaluation processes revealed the need to freeze variables from early stages to the end of those processes. This fact reinforces the role of memory in design. When Dan was asked to reply to Thomas' design, the lack of drawing space caused the following dialogue:

***D:** Okay, so now. Using any elements?*

***J:** Yes.*

***D:** Not just the one he has?*

***J:** It's up to you.*

***D:** So, I could... If I wanted I could start from scratch? But I won't.*

***J:** You can do anything you want, but you have to pick up... refer to what he did, and as you know you have the same task which is to connect the two sides of the board, and you have to replicate...*

***D:** This I can move without cutting and pasting?*

***J:** No. You cannot move his design!*

***D:** Oh, I can't?!*

---

[2] As what? As expected, as possible, as he had done?

J: You cannot. So, are you having troubles with space?

D: Yes. For me at this point I would try to open the center of this up a little bit, and also to reorient some of these elements.

J: Wait. I had an idea. But, you will need to see it.

(removing Thomas' design from the drawing board)

D: So, am I going to loose his (design) entirely?

J: No, what I will try is: to do a new one. Copy this one, and...

D: But I won't be able to see it as I am working? I thought it would have been relatively interesting to take the ones he had, and shift them around.

J: Oh, I see, you don't want to use new elements.

D: Not necessarily. I just wanted to be able to shift what was there.

J: Let me think. I think you should not destroy his composition.

D: What you are saying is, (that) I have to use (). These all must remain, in other words.

J: You should not destroy his composition.

D: But his composition is already saved, right?

J: Yes, but that is not the problem.

D: Humm... I hope I am not making this more difficult than...

Dan's first reaction was to keep the same elements used by Thomas. Thus he would reduce the universe of possible solutions, reducing the set of possible elements to that formed by the elements found in Thomas' design. This way, he would only have to consider the position of those elements in the drawing; other variables associated with the introduction of new elements, such as shape and color, would be frozen.

Furthermore, the visual analysis of both Thomas' and Dan's designs show that Dan did not change Thomas' design radically, despite the fact that he had not been allowed to pursue his initial idea to keep the same elements and shift them around).

In his design, Dan used almost the same type of elements he had found in Thomas' design. Dan used exactly the same number of colors, shapes, and sizes (Table A.IV). Therefore, he worked within the set of parameters provided by Thomas' design.

Dan's evalution process of Thomas' design also exhibited a similar feature. The most evident concern displayed by Dan in his evaluation was whether Thomas composition represented a plan or a section:

> *D: Is this an analog for a three dimensional thing, or is it a purely two dimensional exercise?*

or:

> *D: See, I don't know if he is working in plan or in section, which is interesting.*

This concern is expressed during the entire evaluation process, and it expresses two facts: first, the need to make a definite decision about the representational significance of Thomas' design eliminating, thus, an important part of the range of possible interpretations; and second, the important role that memory also plays in this process. Making a decision about what Thomas was intending to represent, Dan reduced the amount of data he had to deal with.

In this sense, the evaluation process of the critic is much like the design process of the designer. It seems that it can also be represented by a search tree. This point might cause one to speculate on whether designer's evaluation process has the same nature as that of the critic. If so, the design process might be composed of two distinct processes that can be represented by two parallel trees, interacting at common nodes. The results of the experiment are not conclusive in this respect.

7.1.5 Problem Interpretation

Different designers interpret the same design problem in different ways and that has the potential to generate diversity

The problem assigned to Thomas was in fact composed of three different problems: first, to connect the two sides of the drawing board, second, to achieve diversity, and third, to create a whole. Dan was not informed of the two second requirements. He was just told that Thomas had to connect the two sides of the screen, and that he would have to do the same task later on, using the rule he had been able to infer from Thomas' design process:

> *J: He has to connect two points on each side of the screen, from the left to the right.*
> *D: Oh I see, it is something as simple as that.*

Interestingly enough, such a simple task led to rather different interpretations, and these had a significant role in the evolution of Dan's and Thomas' design and evolution processes.

Dan's evaluation process was informed by his interpretation of the task assigned, and he judged Thomas' design within the framework provided by that interpretation which differed from Thomas'. Dan said:

> *D:Now what's he doing? It seems he generates a **series of stops**, rather than an **access**. When you first said one of my reactions might have been to put... or a possible reaction would have been to put an element that even went, thereby establishing completely the dimension, building the complete dimension, and then beginning to generate some kind of system of stops and access that would get... I'm thinking in plan now, although it could be the same in section, but he has done a kind of different thing, he started initially by generating from one side to the other then it seemed like he stopped, changed his mind and built (?) the time to the end. Does he have a time limit?*

After a while, he finally concludes that it has to be a perspective:

> *D: Oh, Oh! It could be... Now, suddenly ,I am seeing, it could be an elevation that he is making. This could be an elevation, I am sorry, not an elevation, but a perspective or an axonometric. I wonder if that is the case. Now that he is putting all these elements it seems almost as if there is a depth, a picture plane depth, perpendicular to the picture plane. I wonder...*

Nevertheless, he was not comfortable with this interpretation either. He started to see the composition as 'too packed':

> *D: (...)If this is in plan or in section, there is no clear route or access from the left edge to the right. The structure doesn't seem very coherent at its largest dimension and he hasn't changed it since, it's beginning too be more packed, but I am not sure to understand what's being accomplished by the packing.*

Thus, he was expressing once more his interpretion of the problem. He moved from a more restricted understanding of Thomas' design under his interpretation of the problem towards a more liberal one, in order to allow his interpretation to survive. He was able to move from one smaller idea to another within the large framework provided by his interpretation, but he was not able to abandon it entirely. He never considered the hypothesis of a non-architectural meaning for the composition.

Dan's own conviction about his way of interpreting the problem was so strong that he insisted to build a plan in his design process, despite his conclusion that Thomas' design could not be a plan, and despite the fact that he was told to follow the same rule:

> *D: What I am trying to do here is still to use these as structural elements, I am going on the assumption that this is in plan, and that he wasn't doing some more spiritual illustration or simulation of space.*

The visual analysis of both designs reinforces the idea that Dan's interpretation of the problem played a determinant role in the evolution of his design process. I have already mentioned that Dan played with the same attributes Thomas had played with in his design, despite the fact that he had been prevented from using Thomas' board. Nevertheless, he used less elements (Table A.IV). Therefore, he simplified Thomas' design by getting rid of some 'extra elements'. He changed Thomas' design because he considered it 'too packed'. For Dan, those extra elements represented too many hurdles in his idea of building an 'access'. Furthermore, he also cared about placing the secondary elements he used on the borders of the composition, and he used horizontal red elements to build the 'frame' that was better suited to his idea of building an access, although he had started using vertical elements as had Thomas. So, not only did he pursue his initial intention of using similar elements to Thomas' design and shifting them around, but he also deviated from Thomas' design to suit his interpretation of the problem.

The assumption that the same problem might suggest radically different interpretations from different designers, and that a chosen interpretation has a determinant role in the design process, is also supported by the analysis of Thomas' design seen from the same perspective. The following portion of the discussion at the end of the experiment is very meaningful in this respect, when Thomas finally describes to Dan the way he understood the problem, and both discuss the subject:

> *J: You were not thinking about a plan or a section.*
>
> *T: No, I have told that. Mine was more of a graphic thing or a perspective, or something...something not tied to a section. As a matter of fact, I was thinking about these things as verticals...*
>
> *D: That's what I thought in the middle...my middle assumption. Instead of this ,seeing it a two dimensional drawing, all of a sudden, I began to see it as a representation of space.*
>
> *T: That has happened at the same time, I started it out as a kind of abstract texture. I was trying to establish this thing from A to B, ...*
>
> *D: ...that's how I saw it, as rythmic generation of the connection...*
>
> *T: ... that connects better than a straight line, and if you have things that go in the direction of the connection then you'll have less options to fill in later. So that was the kind of set up for this "s" form. As soon as I put in the triangles it hit me by surprise as well, that they*

were this kind of tectonic, and that they had a bottom and a top, then it became more of a perspective view.

The thing that gave me the biggest clue about your special thing was this strange empty circle closing off two pieces. Before everything was really graphical. Even though I had the feeling it was a plan but it didn't get this... it was like a move from a conceptual sketch to an actual working drawing. In the beginning I thought he was going to use all the elements that I used.'

So, Thomas' interpretation of the problem had also a determinant role in his design and evaluation processes. Therefore, the same design problem generates different interpretations from different designers, and these in their turn, cause designers to use different generation and evaluation rules. These difference in rules has the potential to generate diversity.

7.1.6 Simplification of Reality

Designers simplify reality and they are biased in this process

Designers tend to simplify reality in order to be able to store a description of reality in their minds. This is a biased process, and it is due to memory limitations. During his evaluation of Thomas' design, Dan perceived that Thomas was not being 'systematic' in his design process:

D: (...),but he has done a kind of different thing, he started initially by generating from one side to the other then it seemed like he stopped, changed his mind and built tears the time to the end. Does he have a time limit?

Nevertheless, he forgot it, and only later when he noticed that a red element was on the top of a black element he rediscovered that Thomas had not been so 'systematic':

D: Let's see, he has also used one of these black elements. I think that is fairly significant how he has used it. Is it going automatically to seat behind or on the top of it? It is on the top isn't it? That's interesting! He must have put this last red piece in later. I had in my mind that this recollection of all the red pieces went in first, which in fact they didn't. And the way I have done it so far is that the way I have done so far is that the only thing that went in before I stopped using the red pieces was this blue one.

Moreover, comparing Dan's and Thomas' design, we can observe that, Dan makes the separation between the 'frame' and the 'infill' more explicit. Unlike Thomas' design, his design had a fewer number of secondary elements. Moreover, while in Thomas' design, the number of secondary elements was even bigger than the number of frame elements (9:6). In Dan's design, the opposite was true (5:6). There is also a clear distinction between 'frame' and 'infill' in terms of color (Table A.V), shape (Table A.VI), and size (Table A.VII).

Therefore, Dan simplified his description of Thomas' design process, and he was biased in this simplication. The fact that Thomas had not been 'systematic' represented a road-block in Dan's theory about Thomas' rule. That suggests that designers simplify reality reducing it to the minimal amount of features enabling them to describe reality in a logical way according to some viewpoint. This mechanism also involves a labelling process. In order to be able later to retrieve the information about reality, and to talk about it, designers need to label the features they find in reality when they store information. For instance, Dan needed to make the generalization 'a frame and an infill' to be able to describe Thomas' design process.

I propose the following explanation for this process: because designers' memories are limited they are not able to store all the information in reality. Therefore, they go through a process of abstraction in order to get rid of minor details. They select the essential features from reality that enable them to construct an internal description of reality. In this process of selection they are biased. Different designers select different features, and thus, they perceive reality differently.

On the other hand, because designers develop their own design processes, and therefore their design solutions, trying to make them logical from a certain viewpoint, they become attached to them. It is difficult for them to generate different solutions for the same problem because they perceive later solutions as comparatively inferior, or because this would imply that their original solutions were less good from that viewpoint. So, it is more difficult for one designer to achieve the same degree of diversity of two or more designers. For instance, if one designers has to design two houses attached to each other, and if there is not any strong constraint that required those houses to be different, he will be more likely to design two rather similar houses. If those houses were designed by different designers, their difference in viewpoints would increase the potential for those houses to be different.

7.1.7 Lack of Complexity

Designers simplification of reality prevents them from achieving complexity

We have just seen that due to memory limitations designers simplify reality to be able to store information about reality, and that this simplification mechanism is a two-step process involving abstraction and labeling processes. Now, I argue that this way of reasoning prevented Dan from achieving in his design the same degree of complexity as Thomas'.

There are more attributes repeated in Thomas' design, but Dan's design is less complex. Through classifying the elements existent in both designs in terms of their attributes (color, shape, and size), one can observe that while Thomas used more than one element of each color, Dan used only one, except for the red elements (Table A.V). Dan also used fewer elements of each shape (Table A.VI). By combining both attributes, color and shape, one sees that the number of unique elements increases (Table A.VII). Only 'empty circles' is repeated. Therefore, one needs both attributes to individualize 'more elements'. Finally, only when one combines the three attributes, is one able to individualize each element in both designs (Table A.VIII). Hence, it is easier to generalize about

Dan's design and more difficult to describe Thomas', making Dan's design less complex than Thomas'.

Complexity is therefore associated with the facility that one can abstract and then describe. Because designers simplify reality in order to build an internal description through abstraction and labelling, when later designers retrieve their internal information about reality in order to construct an external description, this description is comparatively simplified. Therefore, they are not able to reproduce the same degree of complexity of the initial model (Fig. 7.3). Because this new reality is more simplified, its potential to generate different perceptions from an observer is also smaller. Therefore, the observer perceives that reality as being monotonous.

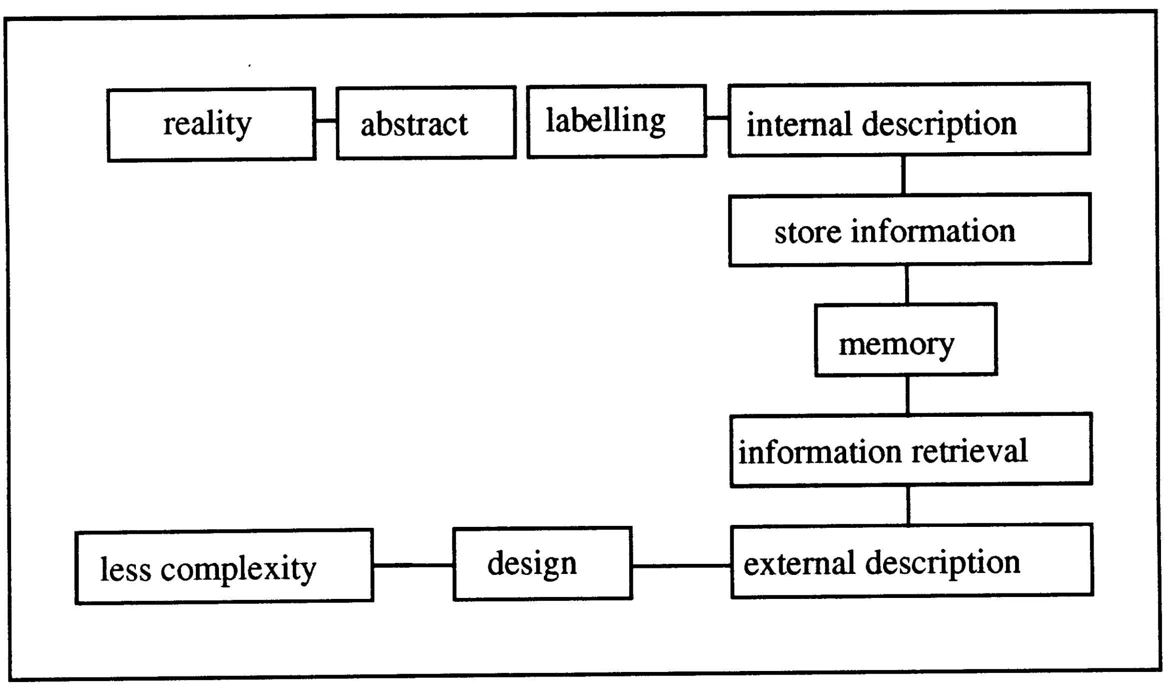


Fig. 7.3
Mechanism of simplification of reality by Designers

7.1.8 Order and Diversity

Order and diversity: two rules guiding the design process
Framework* and *infill
Balance as order: vertical and horizontal balance

Diversity was the critical issue of the task assigned to Thomas. As stated above, he was asked to simply create a design that connected the two sides of the drawing board and was diverse. Nevertheless, beyond making a clear effort to make a diverse composition, Thomas also exhibited a concern for order. His concern for order was manifested at several levels. First he duvided the elements in the composition into *infill* and *framework* elements. Second, on he strove to order each of these groups of elements through balance. Moreover, he manifested a concern for two different types of balance here called vertical and horizontal balance. He used vertical balance to order the whole composition, and both vertical and horizontal balance to order the *framework*.

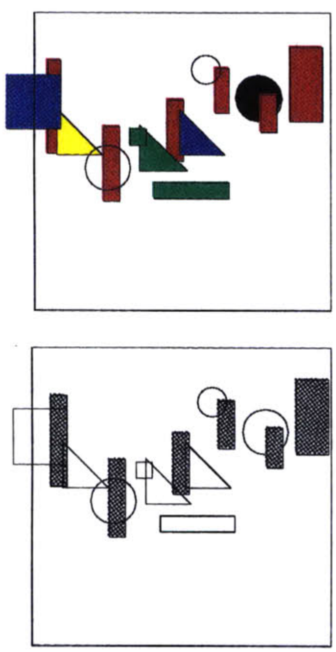


Fig. 7.4
The separation of Thomas' framewor into infill and framework: a concern for order

Thomas' concern for order was first expressed by a clear distinction between *framework*—the red elements and *infill*—the smaller and diverse elements. The structure should tie all the elements together, preventing the composition from falling apart or, using Thomas' words, preventing chaos. The perception of a framework in Thomas' composition, implies a certain degree of abstraction. One has to concentrate on the elements that constitute the framework, and ignore all the other elements. This abstraction, and thus the sense of order, is possible to be understood by the observer because the elements of the framework share features that are distinct from the other elements on the drawing board. This distinct features include: their shape (rectangle), orientation (vertical), and color (red) Fig. 7.4.

In conclusion, Thomas' framework functioned as a guiding theme throughout the composition so that it could be perceived as a whole. Here, Thomas was faced with a problem provoked by the contradiction between the need to have a unifying, and the experimental request to generate diversity. In other words, he had also to vary the theme. The first moves of his

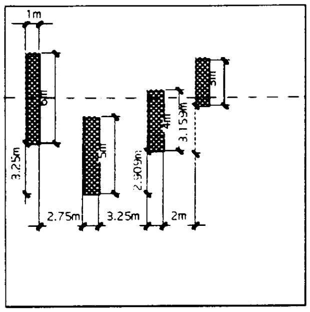


Fig. 7.5
The first four moves of Thomas' design process: a varied framework

design are very meaningful in this respect (Fig. 7.5). Thomas started his design by introducing a big red element on the top left of the drawing board. Then, he introduced a smaller but similar element to the right and below the first one. In his third move, he decided to continue using elements with decreasing length. Nevertheless he placed the new element above the second one, otherwise he would have too much repetition (smaller red elements placed below the previous one). When he placed the fourth red element he had to change again the way the attributes were varying. Therefore, he could not place the fourth element below the third one because that would cause an "up-down-up-down" sequence, and so, he placed it above. At this point one can also argue that he was somehow trying to reach the level of the first element, making the framework horizontally balanced. However, because the length of the elements was decreasing, that was not being achieved.

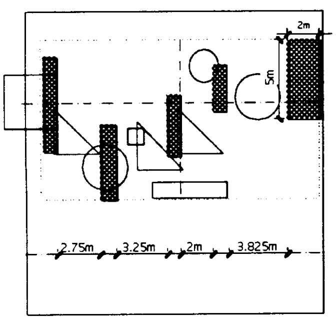


Fig. 7.6
The placement of the 5th framework element: a concern for horizontal balance

After Thomas placed some of the smaller elements he introduced a fifth red element, (Fig. 7.6). He selected a big element which he accidentally enlarged in order to balance the effect caused by the big blue element on the whole composition (see discussion below). This enlarged element was placed at about the same level of the previous red element but, because it was higher and wider than any of the other elements, it seems that it finally reached the horizontal level as the first red element. I argue that the framework at this point achieved a state of horizontal balance. In fact, it seems that the *amount* of red elements above that horizontal reference axis (the axis that crosses the first red element at its midpoint) equals the amount of these elements below.

By introducing this element, Thomas also achieved a higher degree of variety in terms of length (shorter-shorter-shorter-shorter-long), width (one-one-one-one-two), and horizontal relative position (wider-narrower-narrower-wider). However, in terms of the relative vertical since, the vertical position of the last element is almost the same of the previous element. On the other hand, the *amount* of red elements on the left side of the area occupied by the red elements seemed to be greater than the *amount* of these elements on the right side.

Thomas then introduced a sixth red element that he placed between the fourth and the fifth element (Fig. 7.7). I argue that the placement of this element clearly illustrates Thomas' striving for diversity on one hand, and his concern for balance on the other. In fact, since there was no more space in the drawing board after the last red element in the sequence, if Thomas wanted to correct or improve the diversity or the balance of the framework he would have to place a red element between the existing ones. What he did, interrupting, thus, his procedure of placing sequentially the red elements from the left to the right. Only then did he seem to consider the framework finished. This fact was acknowledged by Dan who said:

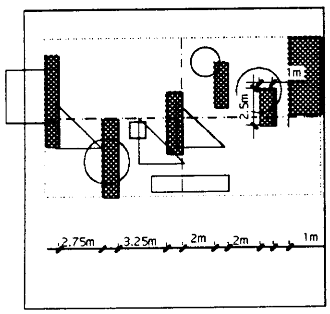


Fig. 7.7
The placement of the 6th framework element:
a concern for diversity and horizontal balance

> *It is interesting he hasn't altered the red elements since he stopped using them.*

I argue that Thomas did not alter the framework further because he considered it both diverse and balanced. In fact, by placing this sixth element, he improved the variety of the relative vertical position of red the elements ("up-down-up-up-up-down-up"), and he also counter-balanced the greater *amount* of these elements existing on the left side. It seems that the framework became vertically balanced. I call this type of balance vertical balance due the position of the axis that is implicitly taken as reference—the axis that divides the area occupied by the framework in two halves.

The idea that Thomas' framework was informed by diversity and balance requirements, is also suggested by a dialogue that Thomas and Dan had at the end of the experiment.

That dialogue (reproduced below) also illustrates how important horizontal balance was in that shaping process.

> *T: I was trying to establish this thing from A to B, ...*
>
> *D: ...that's how I saw it, as rhythmic generation of the connection...*
>
> *T: ... that connects better than a straight line, and if you have things that go in the direction of the connection then you'll have less options to fill in later. So, that was the kind of set up for this "s" form.*

The fact that Dan saw Thomas framework as a rhythmic generation means that he simultaneously perceived it as varied, and repetitive (withou both there cannot be rhythm). The fact that Thomas referred to it as an "s" form means that the variation of Thomas' framework was evolving around a horizontal line, in which the deviations above that line were somehow balanced by the deviations below. Therefore, the dialogue suggests that the framework was simultaneously varied and balanced.

After Thomas placed most of the *framework* elements, he continued his composition trying to balance the placement of an element on the left with the placement of another element on the right. For example, the placement of a yellow triangle on the left (Fig. 7.8-5) was followed by the placement of a blue triangle on the right (Fig. 7.8-6).

> *T: Yes. I had this as an end, and I put that blue thing in order to get a whole and balance a little bit (...).*

Thomas' concern for vertical balance continued throughout his design process. The placement of a blue big square on the left (Fig. 7.8-7) was followed by the placement of a big red element on the right (Fig. 7.8-8) . That, however, seemed not enough to balance the design. The added empty circles did not significantly change the design in terms of balance, and since the design was still unbalanced to the left, Thomas placed a big black circle on the right (Fig. 7.8-11). However, the placement of

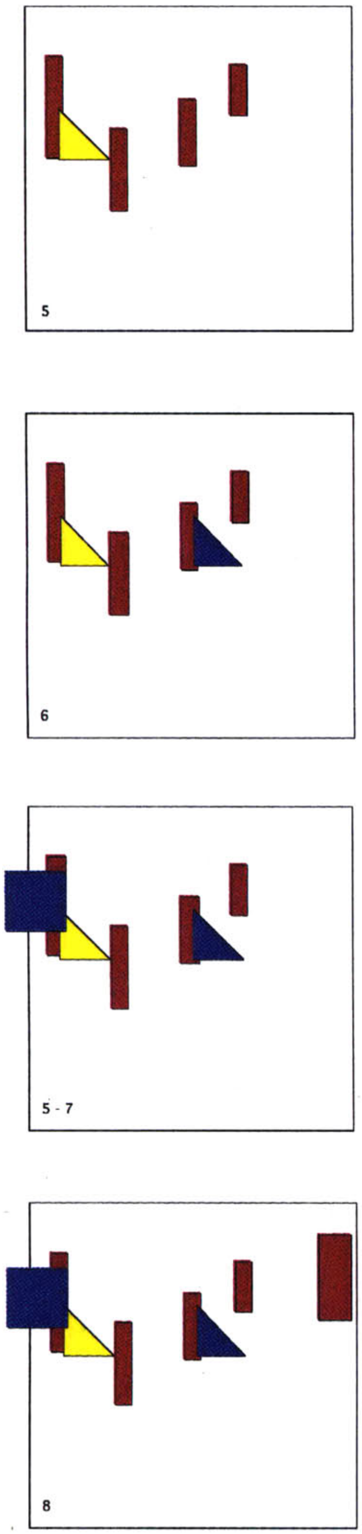


Fig. 7.8
The placement of the infill:
a concern for vertical balance

this black circle, led him to perceive the composition as slightly unbalanced to the right and led him to place a green triangle and a small green square on the left, close to the center of the composition (Fig. 7.8-13 and 14). This seemed to have had the effect of unbalancing again the composition to the left, since he then placed a green rectangle on the right, almost at the center of the composition (Fig. 7.8-15).

The importance of Thomas' procedure is shown by the fact that Dan saw it as meaningful enough to use it in his design process as well. Nevertheless, despite the fact that Thomas' concern for balance was obvious to someone watching him, he himself was not fully aware of it, and later on commented about Dan's design process:

> *T: See, what he does, either he hasn't understood it, which is possible, but I don't think so, or he just works in a different way, he doesn't set up this kind of... he doesn't work as methodological, I think he has a compositional idea. He is balancing this thing while he is going.*

Interestingly enough, Dan's concern for balance was not as obvious as Thomas'.

In conclusion, Thomas' design process was governed by two types of rules, one aiming at diversity, and the other at balance. Diversity was achieved by the use of elements of different colors, shapes, orientations, sizes, and positions, whereas order was achieved first by a clear separation between *infill* and *framework* elements, and then by balance. The *framework* worked as a unifying theme that supported the higher degree of variation of the *infill*. In fact, the *infill* elements were varied, whereas the *framework* elements shared several attributes. Additionally, the infill elements were vertically balanced, whereas the framework elements were also horizontally balanced. An analysis of Dan's design (Fig. B.2), reveals that despite some differences, he followed similar rules. I would argue, that it is significant that when asked to generate diversity both designers displayed a need for order and that order seemed

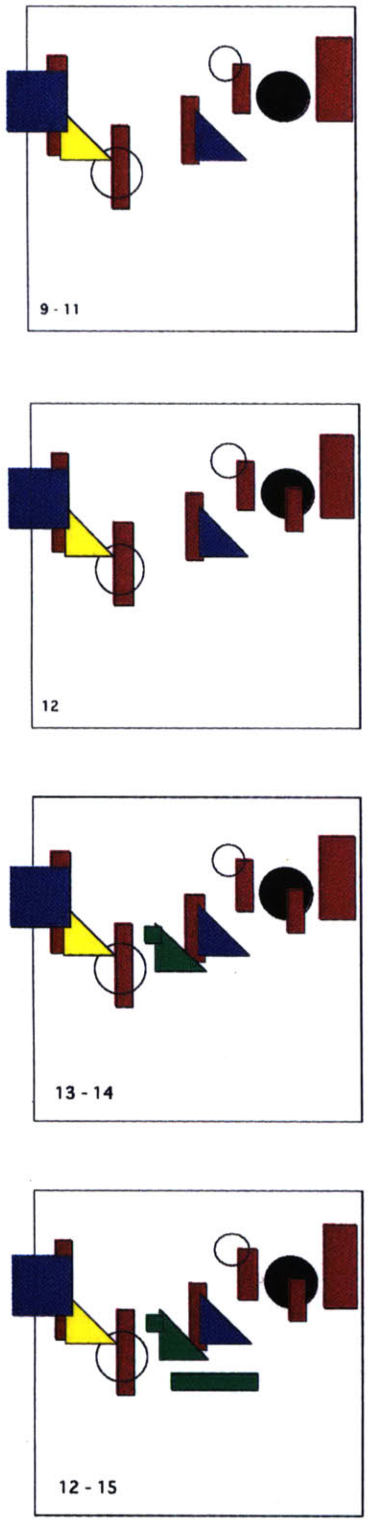


Fig. 7.8 (continued)
The placement on the infill:
a concern for vertical balance

to be strongly connected to the idea of balance. In fact, balance seems to be viewed as a inherently positive feature by designers. Therefore, if one aims for diversity one has also to aim for balance.

7.1.9 A mathematical model for horizontal and vertical balance of *framework* elements

An analogy with music enables the development of a mathematical model for the perception of horizontal and vertical balance of Thomas' framework

In the previous section we showed that Thomas divided his composition into *infill* and *framework* and that he tried to increase the order of his composition by making an ordered *framework*. Additionally, we argued that he ordered the *framework* not only by freezing some of the attributes of its elements such as color, shape, and orientation, but also making other attributes such as size and position, vary in such a way as to make the framework horizontally and vertically balanced. In this section we make a comparison between the way Thomas designed his framework and *tonal* music. This comparison helps to understand Thomas' concern for balance, and to develop mathematical models for the perception of horizontal and vertical balance using shapes like the framework elements of Thomas' composition. The models developed explain Thomas' moves to balance his framework, and can be ultimately used in the development of a computer program that generates groups of elements that have the same type of balance.

The analogy with music assumes that there is a parallel between the way we see compositionally, and the way we listen tonally. It is difficult to precise the extension of this parallelism. It is possible, nevertheless, to argue that there are some other compositions to which the model developed after Thomas' composition can also be applied

a) horizontal balance

In the previous section we argued that Thomas was trying to make the framework of his composition horizontally balanced. It seems that he was somehow varying the framework but struggling to maintain the middle level of the first element. We also argued that the perception of the final design of the framework as horizontally balanced seemed to be given by the existence of equal *amounts* of red elements above and below the axis that crossed the first element at its midpoint. The exact measurements of the total area of red elements above and below

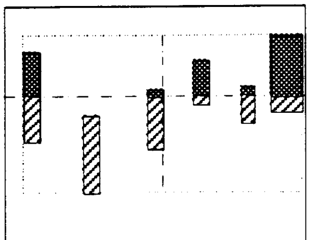


Fig. 7.9
The area of framework elements above the line that crosses the first element at its midpoint is equal to the area below

that reference axis (Appendix A.6) show that, in fact, those areas are almost the same (Fig. 7.9).

This fact enables us to make a step towards a mathematical model that encodes Thomas' concern for horizontal balance. In fact, it suggests that the horizontal line that divides the red elements in two halves of equal area should be very close to the line that crosses the first element at its midpoint that seemed, thus, to have worked as a reference axis. So, if we wanted to check if the framework was in horizontal balance, we would have to find the horizontal mid-area line and then match it with the reference axis. The horizontal mid-area line is, thus, the horizontal compositional axis of the framework.

In order to complete our mathematical model, we still have to discover what the reference axis and the area of red elements represent, and why the midpoint horizontal axis of the first element constitutes the reference axis. The line that crosses the first element at its midpoint is in fact the line that corresponds to the average height of the top and bottom boundaries of that first element, measured relatively to a referential (Fig. 7.10). A comparison with music will help us to address the remaining issues.

Recall that color could not affect the perception of the framework's balance because the framework was made of only one color. However, the x and y location of its elements, as well as their height and width, was very important in this perception. A comparison with *tonal music*[3] is straightforward. The y location of each element's top and bottom corresponds to a different tone in music. The interval between the top and the bottom of each element corresponds to the interval between simultaneous notes, which in music is called *harmonic interval.* A simultaneous play of one or more notes is called a chord. Thus, each element

3 Music based on the division of sound into the seven notes or tones (Do, Re, Mi, Fa, Sol, La, Ti)

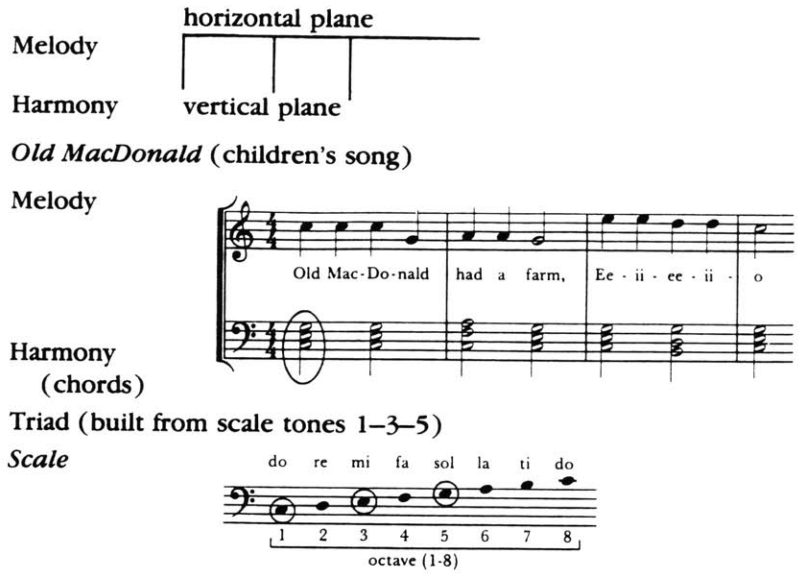


Fig. 7.10
The structure of tonal music: harmony and melody

of Thomas' framework can be seen as a chord of two notes. Finally, the interval between successive elements corresponds to the interval between consecutive notes, which in music is called *melodic interval* (Fig. 7.11).

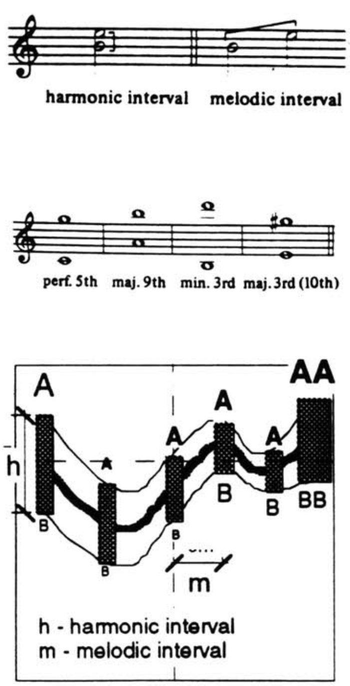


Fig. 7.11
Thomas' framework compared to a music scale

In tonal music, there is a principle called tonality that will help us to understand Thomas' concern for horizontal balance. According to Joseph Machlis,

> *[...] tonality is a principle of organization whereby we hear a piece of music in relation to a central tone, the tonic, and according to a scale or group of notes that is either major or minor. When we listen to a composition in the key of A major we hear a piece in relation to the central tone, according to the major scale built on A and the harmonies formed from that scale.[...]By key, then , we mean a group of related tones with a common center or tonic. These tons revolve around the central tone, the tonic or keynote, to which they ultimately gravitate.* (Machlis 1990)

In our comparison, the major scale corresponds to Thomas' *framework*, whereas the minor scale corresponds to his *infill*. Additionally, key corresponds to the axis around which Thomas' was varying the framework. In other words, the average height of Thomas' first element provided the key for his framework. Therefore, if he wanted the composition to be in that key, he would have to guarantee that, the average height of the framework was the same of the average height of the first element.

The average height of the whole of the framework elements is related to the areas of its elements. In fact, the area tells us for how long the framework remained at a certain level. For instance, for the fourth element, the top level of the framework remained at a y height during 1 unit of length, whereas, the bottom level remained at a height y' for the same unit of length (Fig. 7.12). We understand, thus, why the perception of balance of Thomas' framework was related to the area of its elements. Additionally, we are now ready to propose the mathematical model for horizontal balance.

In the same way we calculate the average height of the first element by calculating the arithmetic average of its top and bottom height, we can calculate the average height of the whole framework by calculating the arithmetic average of its top and bottom heights.

$$ha = \frac{hay + hay'}{2}$$

ha - total average height of the set of elements
hay - top average height of the set of elements
hay' - bottom average height of the set of elements

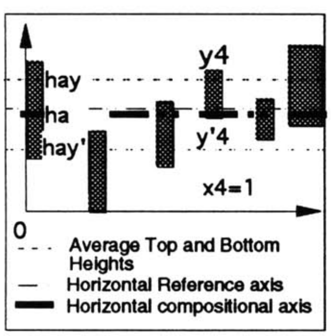


Fig. 7.12
The horizontal reference and compositional axes of Thomas' framework

The average top and bottom heights of the whole framework are, in their turn, the result of the arithmetic average of the top and bottom heights of each element that constitutes the framework. These values are, then, given by the following formulas:

$$h_{ay} = \frac{y_1 x_1 + y_2 x_2 + \dots + y_n x_n}{x_1 + x_2 + \dots + x_n}$$

(1) average top height formula

y_1 - height of the top boundary of element 1
x_1 - width of the element 1

$$h_{ay'} = \frac{y'_1 x_1 + y'_2 x_2 + \dots + y'_n x_n}{x_1 + x_2 + \dots + x_n}$$

(2) average bottom height formula

y'_1 - height of the bottom boundary of element 1
x_1 - width of the element 1

These average upper and bottom heights can be represented by two lines parallel to the x axis whose y coordinates are the average upper and bottom height values (Fig. 7.12). From the average top and bottom values we finally deduce the formula that prompts the average height of the whole framework:

$$h_a = \frac{((y_1+y_1')/2)x_1 + ((y_2+y_2')/2)x_2 + \dots + ((y_n+y_n')/2)\, x_n}{x_1 + x_2 + \dots + x_n}$$

or

$$h_a = \frac{(y_1+y_1')x_1 + (y_2+y_2')x_2 + \dots + (y_n+y_n')\, x_n}{2(x_1 + x_2 + \dots + x_n)}$$

(3) average height formula

To calculate the average height value is equivalent to finding the line that is between the upper and the bottom average level lines. This line is the mid-area line of the group of elements, and so it is the one that should be compared with the reference line. When the two lines are coincident, the composition is in horizontal balance relatively to that reference line. In conclusion, the average height line of the whole framework is also its horizontal compositional axis.

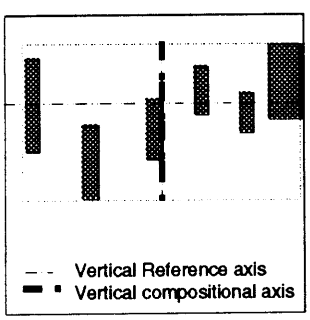


Fig. 7.13
The middle horizontal axis of the area occupied by the framework as a reference axis

There is still one issue that has not yet been explained: why did Thomas select the average height of the first element as a reference? In fact he could have selected other references such as the middle horizontal axis of the area occupied by the drawing board (Fig. 7.13). Tonal music can also help us in this regard. According to Machlis:

[...} This "loyalty to the tonic" is fostered in us by much of the music that we hear. It is the unifying force in the do-re-mi-fa-sol-la-ti-do scale [...].

Tonality, needless to say, resides in our minds rather than in the tones themselves. It underlies the whole system of relationships among tones [...] such relationships converging upon the "definite point of repose" mentioned in the [following] statement by Stravinsky.(Machlis 1990)

"All music is nothing more than a succession of impulses that converge towards a definite point of repose" (Stravinsky, quoted in Machlis, 1990)

According to the statements above, we can argue that Thomas was in fact trying to make his composition returning to the departing point: to the initial average height, and ultimately to the point of repose. This idea of a cycle that leads to the departing point is also reinforced by Thomas' strive for balancing vertically the framework, as we will explain in following.

b) vertical balance

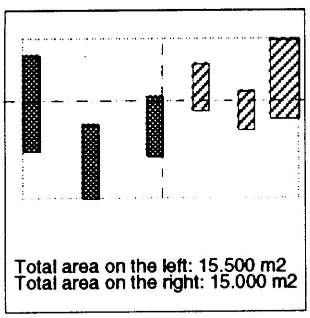


Fig. 7.15
The area of framework elements on the left side of the drawing board area ocuupied by the framework is equal to the area on the right side

In Section 7.1.8 we argue that Thomas was also trying to vertically balance his framework. We also argued that the perception of the framework as vertically balanced seemed to be given by the existence of equal amounts of its elements to the left and to the right of the area occupied by the framework. The calculation of the areas to the left and to the right of the central axis of the drawing board (Appendix A.6) show that, in fact, those areas are almost the same (Fig. 7.15).

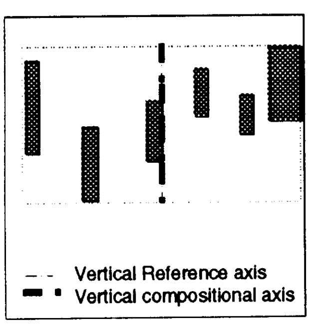


Fig. 7.16
The vertical and reference axes of Thomas' framework

In a similar way to the mathematical model proposed for horizontal balanced, we can develop a model for vertical balance. This model assumes the existence of a reference axis—the vertical axis that divides the area occupied by the framework in two halves—and a compositional axis—the vertical mid-area axis (Fig. 7.16). According to the model, the framework is in vertical balance when the mid-area axis coincides with the reference axis. The deduction of the formulas that support the model is straightforward, and very similar to the formulas we proposed for vertical balance. Thus, we will not present them in here.

A comparison between vertical balance, and music is not as direct as for horizontal balance. It is, nevertheless, possible as referred above, and as we will show in following. This comparison is useful because it help us to understand Thomas' strive for vertical balance. Our comparison between design and music is not original. Vitruvius in his *Ten Books on Architecture* dedicates an entire chapter to *Harmonics* (Book V, Chapter iV), and in the subsequent chapter he makes a comparison between the proper arrangement of vessels in a theater, and a musical theme:

> *In accordance with the foregoing investigations on mathematical principles, let bronze vessels be made, proportionate to the size of the theatre, and let them be so fashioned that, when touched, they may produce with another, the notes of the fourth, the fifth, and so on up to the double octave. Then having constructed niches in between the seats of the theatre, let the vessels be arranged in them, in accordance with musical laws, in such a way that they nowhere touch the wall, but have a clear space all round them in room over their tops. [...]*

Then Vitruvius give detailed descriptions of how to place the statues according to the notes they represent. And illustrates the arrangement described with the a musical scale presented in Fig. 7.17.

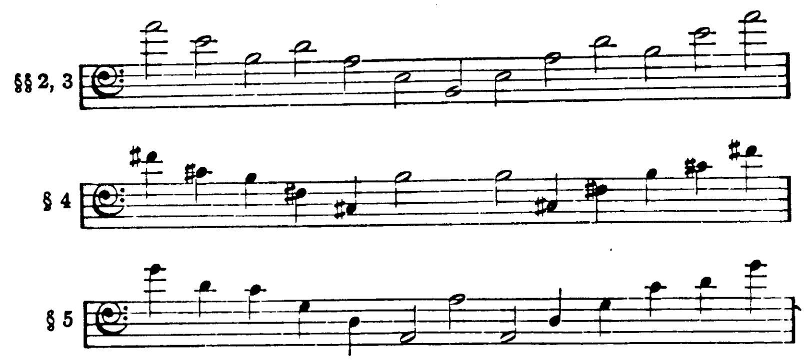


Fig. 7.17
The arrangement of Vessels in a theater according to Vitruvius translated to a musical scale

Note how the melody that the placement of the statues represents is in a perfect vertical balance. In fact, it is absolutely symmetrical. The existence of symmetries and other forms of vertical balance in music is not uncommon. See for example, the passage from a work by Debussy shown in Fig. 7.18-1 and the passage from Grands Etudes after Paganini by Liszt shown in Fig 7.18-2.

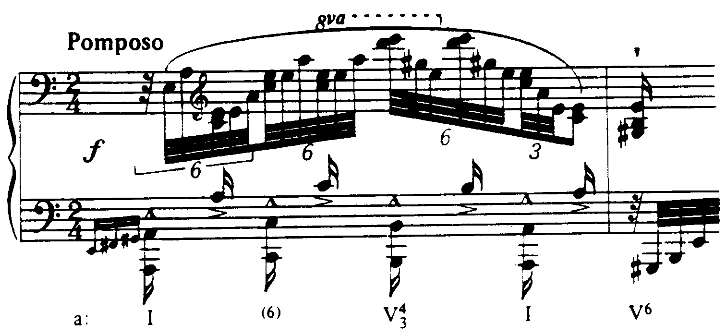


Fig. 7.18
Passages from L'isle joyeusse by Debussy, (1) and from the Grands Etudes after Paganini by Liszt (2). Two examples of vertical balance in music

In order to understand the existence of this type of balance in music, we have to recall Stravinsky's idea that music converges towards a point of repose. The use of vertical balance in music helps us to understand its use in design. However, I argue that there is a factor in which design is different from music that causes the use of vertical balance in design to be even more common. We cannot appreciate a work of music all at once; it requires a time sequence. We can, nevertheless, appreciate many designs with a single look. We are then in a much better position to appreciate vertical balance.

c) The explanation of the design process of Thomas' framework using the formulas

As a way of conclusion, we show that the mathematical models we propose for horizontal and vertical balance are accurate in explaining the design of Thomas' framework from the balance viewpoint. This design process is illustrated in Fig. 23. An analysis of this figure shows that the final state of the framework (6) is the one in which the framework presents a better combination of both vertical and horizontal equilibrium. In fact, in that state, the vertical compositional axis is coincident with the vertical reference axis, and the horizontal compositional axis is also very close to the horizontal reference axis. In the previous state (5), the composition presented a slightly better horizontal balance, but a much worse vertical balance.

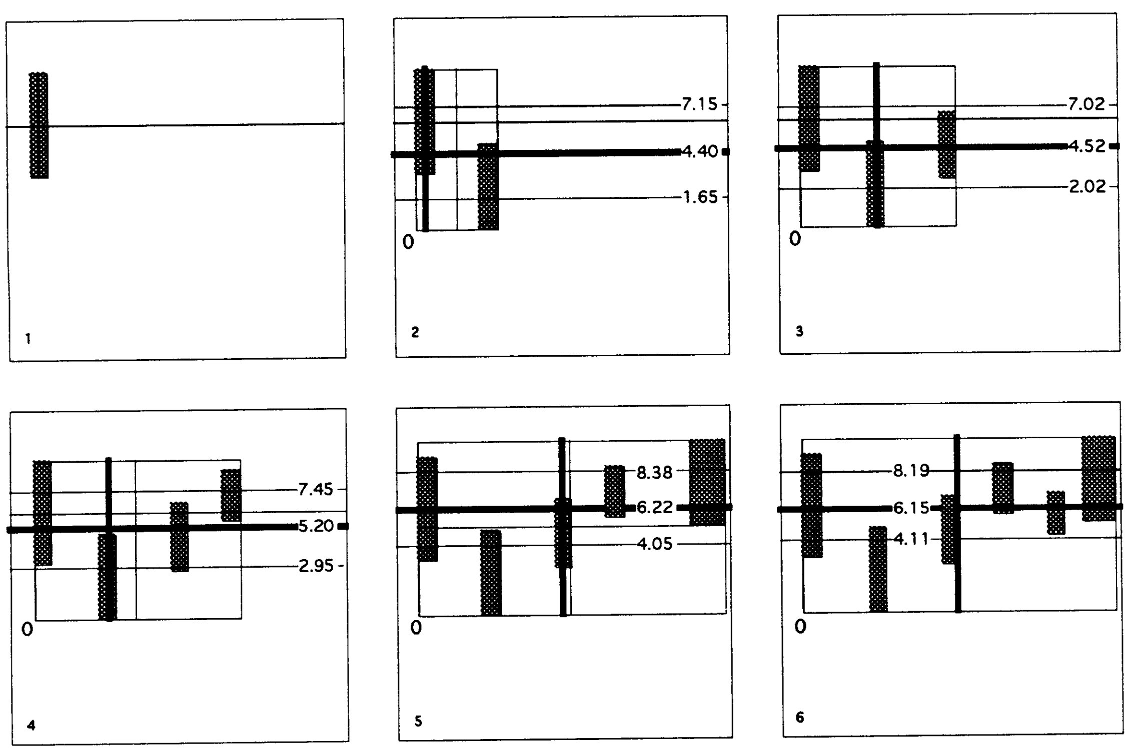


Fig. 7.19
Analysis of the design process of Thomas' framework in terms of vertical and horizontal balance

In conclusion, we proposed in this section two mathematical models for the perception of balance. One for horizontal balance, and another for vertical balance. These models were based on the analysis of Thomas' composition, and an analogy with music. The models succeed in explaining the development of Thomas' framework, and I believe that the use of these models can be extended to other compositions in which there is a *background theme* like Thomas' *framework*. The models assume the existence of a reference axis and a compositional axis. In order for the *background theme* to be perceived as in balance, the compositional axis should be coincident with the reference axis or , at least, be very close to it. In the model for horizontal balance the average height line of the framework is the compositional axis, whereas the average height of the first element is the reference axis. In the model for horizontal balance, the vertical mid-area axis of the framework is the compositional axis, and the vertical mid-axis of the area occupied by the framework is the reference axis. Based on the analogy with music and considering the meaning of horizontal and vertical balance, I argue that the compositional axes are constant from composition to composition, whereas the reference axes might vary. In other words, and to use the analogy with music, the key is always the note around which the music evolves, but it does not necessarily have to be the first note in the composition. In music, though, the first note is often the key.

7.1.10 - Mathematical model for vertical balance

A gravity metaphor as a technique enables the development of a mathematical model for vertical balance

In section 7.1.8, we saw how Thomas divided his composition into *infill* and *framework*, and how he used horizontal and vertical balance to order the framework, and vertical balance to order the whole composition. In the previous section we proposed mathematical models to describe the perceptions of horizontal and vertical balance in Thomas's framework. The perception of these two types of balance in the framework seemed to be strongly related, and function in similar ways. Thus, the models proposed for each type of balance were very similar to each other. The perception of *vertical balance in the whole composition*, however, seems to function differently. Unlike in the framework, the color and the horizontal position of the shapes used in the composition seems to influence the perception of balance. So, the mathematical model for this type of balance, has to be different. In this section, we use a gravity metaphor as a technique for the development of such model. The model is applicable to both colored and non-colored compositions, and can be used to encode the perception of this type of balance into a computer program.

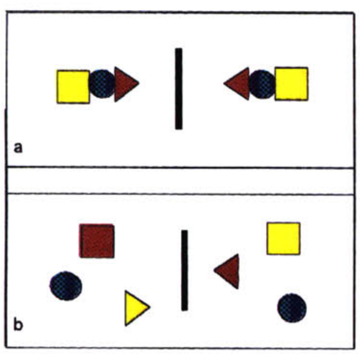


Fig. 7.20
The achievement of order experienced through balance is straightforward in a symmetrical composition, but if diversity is a requirement the task is more complicated

In order to equilibrate the plates of a balance, one has to place equal weights on each plate. The easiest way to do so is to use volumes that have the same weight. However, if one does not have access to volumes that weigh the same, one has to combine different weights, which makes the task slightly more complicated. Similarly, the easiest way to produce a balanced composition is to make a symmetrical composition. This implies the existence of an axis and acceptance that both sides of the composition are equal. Throughout the history of architecture, one finds many examples of symmetry associated with the idea of ideal plans or facades. However, if one is concerned with diversity, one has necessarily to avoid the use of symmetry, at least to a certain extent. Therefore, one is faced with the problem of achieving balance using different compositional elements on each side of the composition (Fig. 7.20).

How does one experience the sense of balance in that circumstance? Papazian and Fargas introduced the idea (Papazian, 1991) that people use metaphors in design. In other words, they draw a parallel with other phenomenon that they understand and that helps them to assess their design problem. True or not, the idea seems to be powerful and useful if one intends to translate design knowledge into a computer program. I propose here to use a common balance as a metaphor for visual balance. How do people then assess the different elements in terms of weight? Suppose that all the elements have the same color. The area of a shape seems to be an attribute used to judge its visual weight (Fig. 7.21). We find this phenomenon in Thomas' design process. When the composition was strongly unbalanced, Thomas introduced large elements (for instance, move 8—Fig. 7.23), whereas when the composition was almost in balance, we placed small elements (for instance, move 14—Fig. 7.23-14).

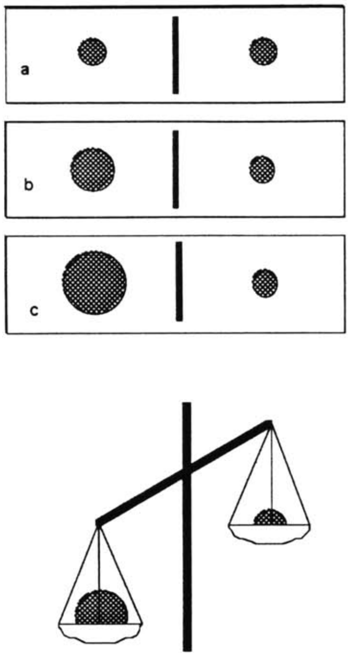


Fig. 7.21
The area of a shape influences the perception of its visual weight. In diagram a the composition looks in balance, whereas in diagrams b and c larger shapes on the left make them look unbalanced

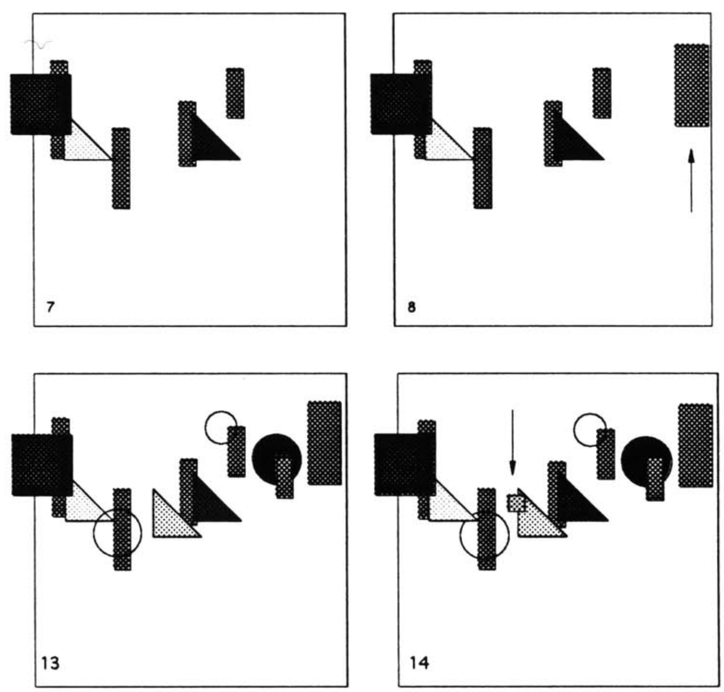


Fig. 7.22
Thomas placed big elements to balance the composition when it was unbalanced, and small elements to prevent unbalancing it when it was balanced

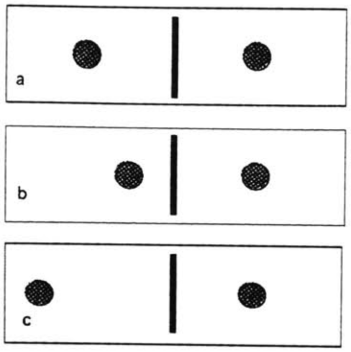


Fig. 7.23
The distance of a shape from the center of a composition influences the perception of its visual weight. In diagram a the composition looks in balance, whereas in diagrams b and c it looks unbalanced

However, area alone is not enough. Like in a scale thedistance of a plate from the center influences balance, the distance of a shape to a reference axis influences the judgement of its visual weight (Fig. 7.23). The closer a shape is to the reference axis, the lighter it looks, and vice-versa. We find several examples of the influence of distance on the perception of visual balance in Thomas' design. When Thomas needed desperately to balance the composition, he placed new elements as far as possible from the center (move 8, and move 11—Fig. 7.24-11), or when he was close to achieving balance he placed them near the center (move 13—Fig. 7.24-2, move 14, and move 15).

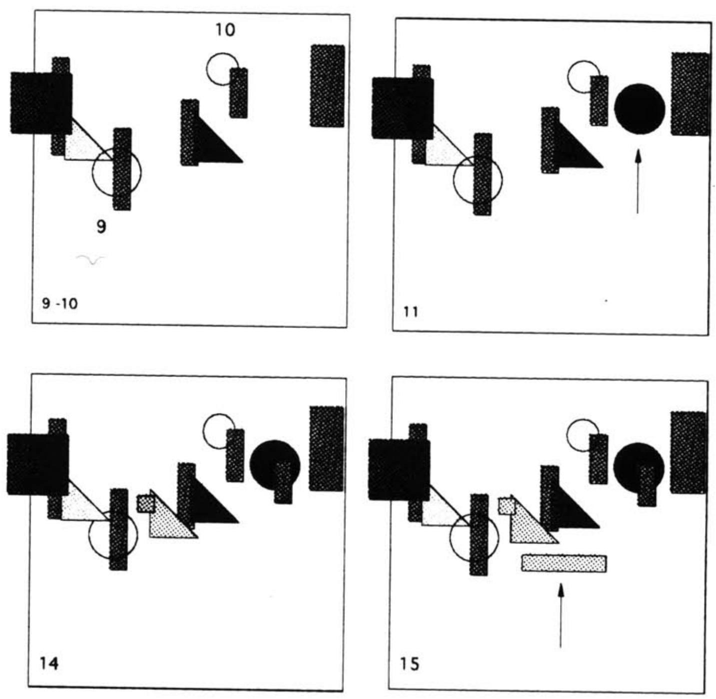


Fig. 7.24
Thomas placed new elements far away from the center to balance the composition when it was unbalanced, and close to the center when it was almost balnced

The axis of the drawing board as the reference axis. The visual impact of the blue square stepping out of the drawing board makes difficult it to accept this axis as the only reference axis

The axis of the designed area as the reference axis. The important presence of the drawing board frame makes also difficult to accept this axis as the one reference axis

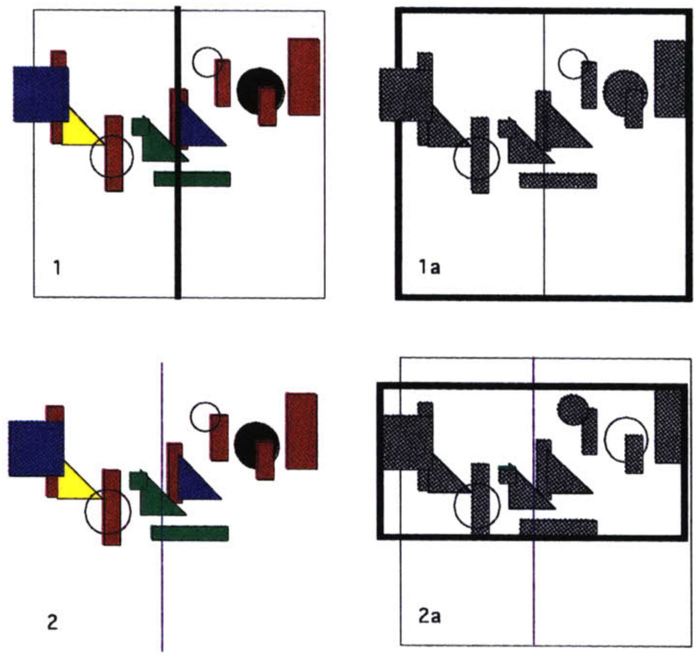


Fig. 7.25
The two reference axes of Thomas' design process: the axis of the drawing board (a), and the axis of the designed area (b)

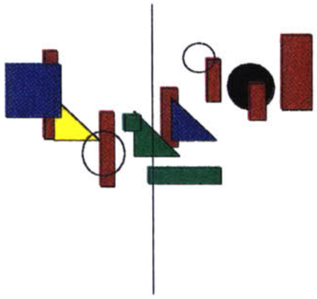
But what exactly was the reference center? Thomas' design seemed to have two different virtual reference axes: the axis of the drawing board (Fig. 7.25-a), and the axis of the area occupied by the design (Fig. 7.25-b).

Therefore, to judge if the composition was in balance he would have to measure the distance of the virtual axis of his composition to those two axes. That is the virtual axis of his composition can be defined as the axis according to which the composition could be perceived to be in balance. We are now in conditions to propose a mathematical formula for visual balance after the Physics formula to calculate the center of mass:

$$x = \frac{A_1 D_1 + A_2 D_2 + \ldots + A_n D_n}{A_1 + A_2 + \ldots + A_n}$$

(1) Vertical Visual Balance Formula

x - x coordinate of the compositional balance axis
A - Area of the shape
D - Distance of the shape center to the origin



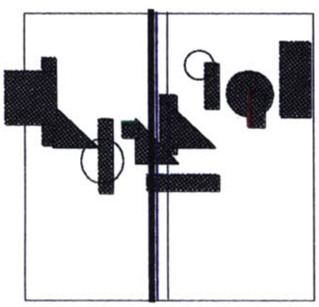


Fig. 7.26
Thomas' composition does not look in balance relatively to the axis calculated by the Visual Balance Formula (1) that assumes that color does not affect the perception of visual balance

The masses M1, M2,..., Mm in the original formula are substituted in our formula by the areas A1, A2,...,An of each shape in a two dimensional composition (or the volume in a three dimensional one), and D1, D2,...,Dn remain the distances of each shape to the origin of a Cartesian referential.

The calculation of the compositional axis x coordinate of Thomas' design process using this formula is shown in Appendix A.6, and an interpretation of Thomas' design using that axis is provided in Figure A.3. Since this interpretation assumes that color does not affect the perception of balance, the different colors can be represented by the same gray tone. Although this interpretation may roughly explain Thomas' design process from the balance viewpoint it is not, in fact, accurate. For instance, if we consider the virtual axis defined by the formula, and match it against the final design, we see that the composition does not seem in balance relatively to this axis; the axis seems to be too on the left (Fig. 7.26)[4]

Other inefficiencies can be found by matching the Graphic Protocol presented in Fig. A.1 with the interpretation of Fig. A.3. For instance, the theory suggests that the yellow triangle added to the composition unbalanced it more than its perceived visual weight seems to suggest (Fig. 27-5a/Fig. 27-5b), or that the black circle added later did not balance the composition, when its perceived visual weight suggests that it did (Fig.27-11a/Fig. 27-11b).

We are then led to the hypothesis that a shape's color affects the perception of its visual weight. In fact, if we look at same sized shapes that have different colors, we see that some look "heavier" than others. For instance, blue looks heavier than yellow against a white background (Fig. 7.28).

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[4] In this interpretation I considered that the placement of the empty circles did not affect the balance of Thomas' composition.

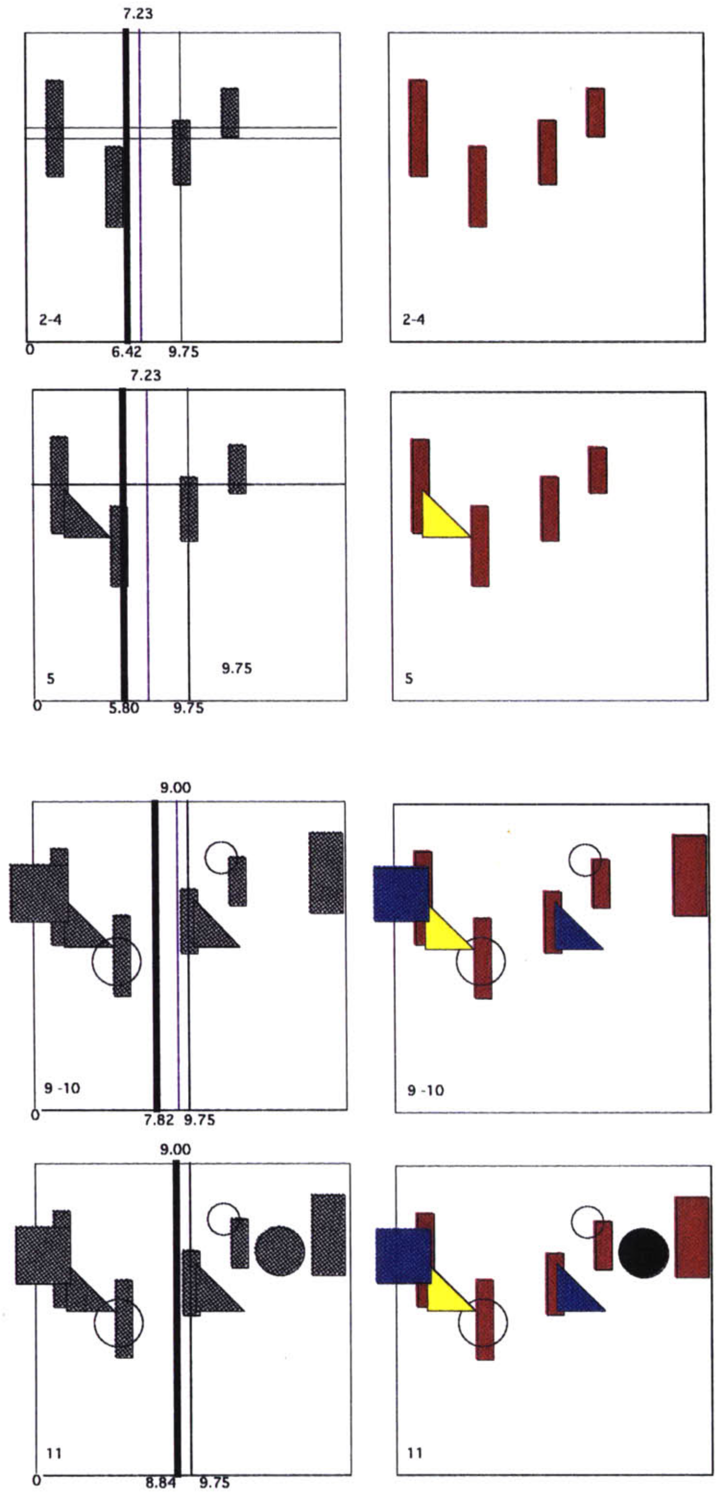


Fig. 7.27
The theory that different colors have the same visual weights fails to explain accurately some moves of Thomas' design process (see text on previous page)

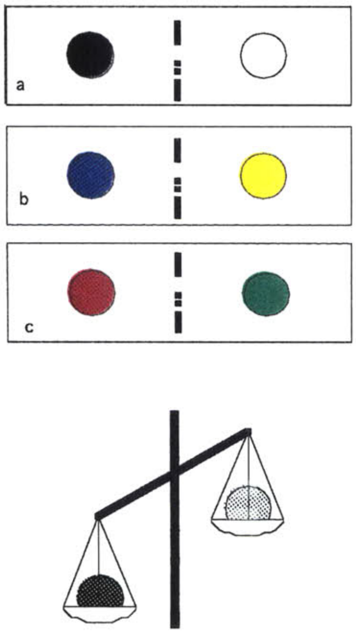


Fig. 7.28
The color of a shape influences the perception of its visual weight: darker colors look heavier whereas lighter colors look lighter

A careful look also suggests that darker shapes look "heavier" than "lighter" ones (it is meaningful that the words in English to express the opposite of heavy and dark are one and the same). Therefore, by converting all colors onto a gray scale, one would be able to order them according their visual weight. From color theory one knows that any set of three colors combined in a certain proportion can be used to obtain all the colors. Red, green, and blue are the colors most commonly used for this purpose, such as for data image processing devices like computer monitors and televisions. A formula that transforms colors into a gray tone by calculating their degrees of whiteness according to their RGB values has already been obtained (Pennebaker, 1993), and is shown below.

$$y = 0.299\,R + 0.587\,G + 0.114\,B \qquad \text{(2) Gray Index Formula}$$

y - White Index (degree of whiteness)
R - Red
G - Green
B - Blue

According to this formula, if we combine red, green, and blue colors whose RGB values are maximum (in a scale from zero to 65535) in the right proportion, we obtain a pure white color. White has, thus, the highest degree of whiteness (65535), and black the lowest (zero). The inference of the formula that returns the value of a color measured against black, as we need for our visual balance formula, instead of against white is then straightforward:

$$w = \frac{65535 - y}{65535} \qquad \text{(3) Color Weight Index Formula}$$

w - Color Weight Index (degree of blackness)
y - White Index

By subtracting the white index of a given color from 65535 we obtain a value that measures its degree of blackness instead of whiteness. By dividing that value by 65535, we assure that the degrees of blackness will have any value between zero (white) and one (black). Figure 7.29 shows the conversion of principal colors to gray tones. Since darker colors look heavier, the degree of blackness of a given color measures also its visual weight. Therefore, the coefficient obtained by formula (3) can be called Color Weight Index, and can be used to complete the formula (1) presented above.

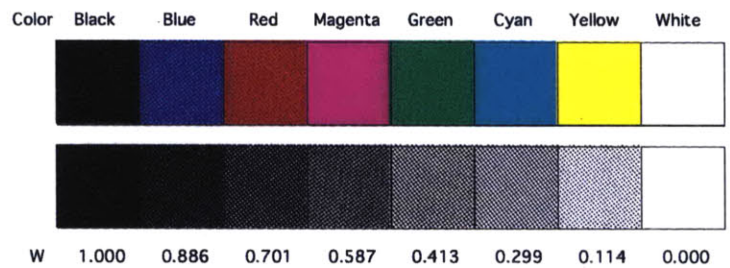


Fig. 7.29
Conversion of principal colors to a gray scale made possible by ordering them according to their heaviness measured against white

The new visual balance formula would then be:

$$x = \frac{w\,A1\;D1 + w\,A2\;D2 + \ldots + w\;An\;Dn}{w\,A1 + w\;A2 + \ldots + w\;An}$$

(4) Vertical Visual Balance Formula

x - x coordinate of the compositional balance axis
w - Color Weighting Indexes of each shape color
a - Area of the shape
d - Distance of the shape center to the origin

According to this new formula, the placement of a big dark shape far from the center of the composition would have a maximum effect on the balance of a given composition, whereas the placement of a shape whose center was coincident with the axis, or the placement of a white shape would have a zero effect.

The calculation of the compositional axis x coordinate of Thomas' design process using this formula is shown in Appendix A.6, and an interpretation of Thomas' design using that axis is provided in Fig. 31 (note that colors were transformed into their correspondent gray tones). The interpretation under this new

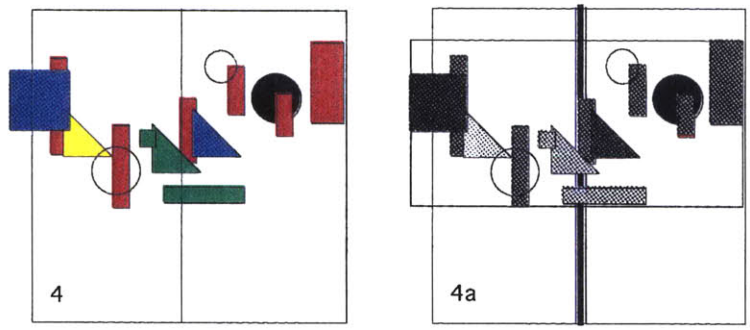


Fig. 7.30
Thomas' composition looks in balance relatively to the axis calculated by the Visual Balance Formula (4) that assumes that different colors have different visual weights

formula does not have the flaws of the previous interpretation. For instance, the composition looks in balance when judged relatively to the axis calculated according to formula (4). In fact, this axis is between the two reference axis (Fig. 7.30), which is logical since we can assume that Thomas was looking alternately at both axes .

A comparison of figure A.4 with the Graphic Protocol presented in Fig. A.1, shows that the interpretation under this new formula (Fig.7.31) not only explains Thomas' final design but also the sequences of moves of his design process. A brief description of Thomas' design process from the balance viewpoint after the formula is given below, and a detailed description, both from the two viewpoint of diversity, and from the viewpoint of balance is provided in Fig. A.5 .

After Thomas placed the first red elements of his framework, with the concern to make them as varied as possible, he placed a yellow triangle because he did not perceive the composition as enough diverse (Fig. 7.31-5). The placement of this yellow triangle did not significantly change the perception of balance in the composition, which was already heavier on the right, since the introduction of the yellow, light triangle was compensated by the partial hiding of the red, heavier, rectangle. Thomas then placed a blue (for the sake of diversity) triangle on the right (Fig. 7.31-6/Fig. 7.31-6) that balanced the composition relatively to the axis of the designed

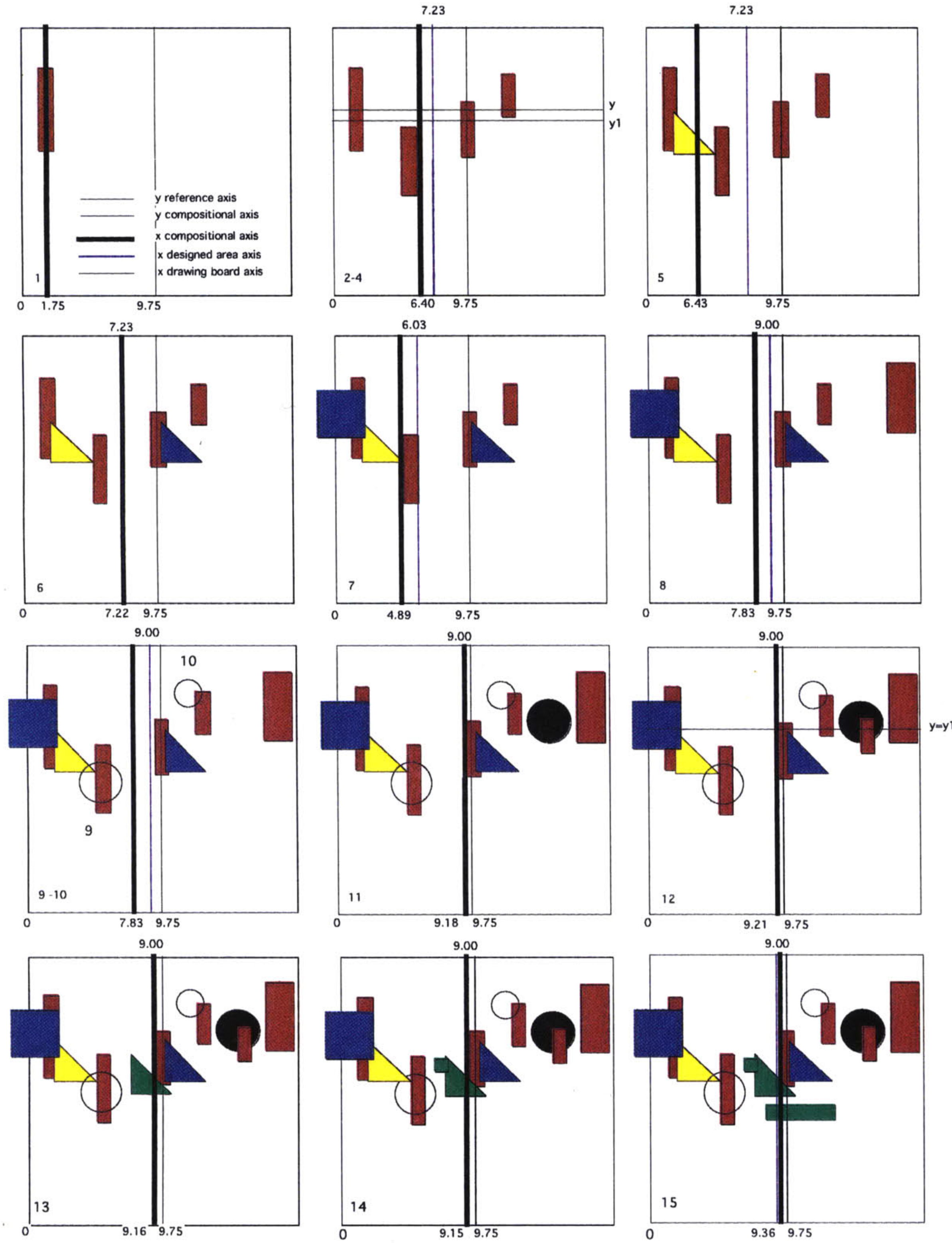


Fig. 31
Analysis of Thomas' design process from the balance viewpoint assuming that different colors have different visual weights

area. The placement of a blue rectangle on the left (Fig. 7.31-7), outside the drawing board, in order to express his idea of a path connecting the two sides of the drawing board, unbalanced the drawing board to the left again. The placement of an accidentally enlarged, heavy, red rectangle on the right (Fig. 7.31-8), almost horizontally balanced the framework, and moved the axis of the design close to the axis of the drawing board. However, the composition was still heavier on the right. The placement of white, empty and light circles (Fig. 7.31-9,10) did not affect the compositional balance, whereas the placement of the black, heavier circle (Fig. 7.31-11) almost balanced the composition. The subsequent placement of the red rectangle on the right, overlapping the black, heavier circle (7.31-12), diminished the visual weight of the circle, moving the vertical axis of the composition only slightly to the right. It also horizontally balanced the red framework. The placement of the green triangle, and the green small square, close to the center of the composition (Fig. 7.31-13,14), slightly moved the center of the composition to the left, closer to axis of the designed area. Finally, the placement of a green rectangle, close to the center of the composition but slightly to the right (Fig. 7.31-15), moved the center of the composition again to the right, midway between the two reference axis. The composition looks, thus, in balance. The success of this interpretation in describing Thomas' design process, proves the validity of the Visual Balance Formula proposed here.

The discussion above assumes that all colors were being measured against a white background, which is correct in the case of Thomas' design. But what if the background were not white but of a different color? How would that affect the perception of a given color weight? See, for instance, Figure 7.32. The Yin and the Yang, the oriental symbol of perfect balance is placed against a black, a white, and a gray background.

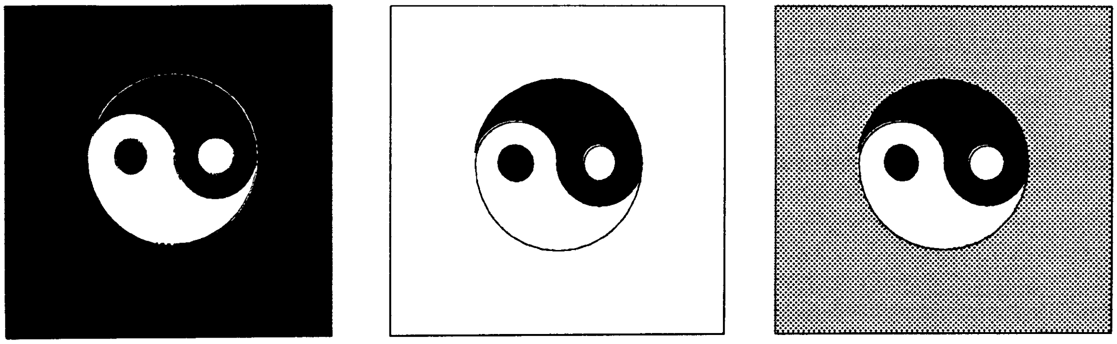


Fig. 7.32
The yin and yang; the oriental symbol of balance and harmony. The background influences the perception of balance

The symbol itself can be viewed as the symbol for the kind of balance being discussed here. See how the background affects the perception of balance. The symbol looks balanced only when it is placed against an intermediate gray (midway between white and black) background. Against such a background, both white and black have the same value. It seems obvious that the visual weight of a shape depends on its background. Therefore, the Color Weight Index of a shape's color, to be used in the formula proposed, is the deviation of the Color Weight Index of the shape's color measured against a white background, from the Color Weight Index of the shape's background color measured against a white background. The Visual Balance Formula is then:

$$x = \frac{(w1 - wb) * A1\ D1 + (w2 - wb) * A2\ D2 + \ldots + (wn - wb) * An\ Dn}{(w1 - wb) * A1 + (w2 - wb) * A2 + \ldots + (wn - wb) * An}$$

(5) Vertical Visual Balance Formula

x - x coordinate of the compositional balance axis
w1...n - Color Weight Indexes of each shape color relatively to white
wb - Color Weight Indexes of the background relatively to white
A - Area of the shape
D - Distance of the shape center to the origin
*(wn - wb) - Color weight of the shape relatively to the background if wn>wb
*(wb - wn) - Color weight of the shape relatively to the background if wb>wn

In conclusion, the use of the weight metaphor to represent visual balance of a given composition enables us to use mathematical functions to encode the rules that simulates balance perception. The proposed strategy assumes the existence of reference axes and that the perception of balance is influenced by the size, color, and location of its shapes, as well as by the color of its background. The need to achieve diversity prevents designers from generating clearly symmetrical designs. Diversity requires them to judge the shapes in a composition in terms of color, size and location, thus making the achievement of order more difficult. The encoding of the rule for order expressed by the visual balance formula enables us to program the computer to generate compositions that are diverse but perceived as ordered by a human observer.

7.1.11 Previous approaches to visual balance

The mathematical model proposed for vertical balance is in accordance in many aspects with previous approaches to visual balance.

It does not take into account, however, factors connected to the cultural background of the observers that might also affect the perception of visual balance

Although not providing any mathematical balance for visual balance in compositions, there are studies that have already addressed the issue. "Art and Visual Perception" by Rudolf Arnheim (Arnheim, 1974) is one of them. In his book Arnheim considers two main factors affecting the perception of balance in a composition: weight and direction. Weight of shapes in a composition is a consequence of other attributes such as location, size, color, isolation, shape, spatial depth, intrinsic interest, and knowledge of the observer. As to location and size, his observations confirm mine, but those of color do not agree. He says:

> *As to color, red is heavier than blue, and bright colors are heavier than dark ones. The patch of a bright red bedcover in Van Gogh's painting of his bedroom creates a strong off-center weight. A black area must be larger than a white one to counterbalance it; this is due in part to irradiation, which makes a bright surface look relatively larger.*

Color

A look at Van Gogh's painting mentioned by him allows us to find the source of his interpretation. In fact, in that picture, the bright red bed cover does look heavier than any other object. His observation seems to be correct, but I would hold that this occurs only because of the darkness of the background. The visual weight of a given color depends on its background color. It might be opportune to introduce another remark required by other studies on color vision (Feynman, 1977, Encyclopedia Britannica 1991). These studies show that the degree of illumination in the observer's environment also influences the perception of color. Colors that look bright under bright light might look darker under dark light, and vice-versa. Therefore, the perception of the visual weight of a certain object's color depends on the color itself, on the background's color, and on the environment's degree of illumination.

Intrinsic interest

As to intrinsic interest, and knowledge of the observer, I think that his remarks are accurate, and in accordance with my explanation, in which is implicit the existence of reference axes, that inform the perception of balance. The selection of such axes depends, obviously, on what the observer decides to focus, and that likely depends also on his or her cultural background. As to isolation he notes that

> *Isolation makes for weight. The sun or the moon in an empty sky is heavier than an object of similar appearance surrounded by other things.*

Shape

I have no basis to agree or disagree with his statement about isolation, but I do not fully agree with his assumption about shape:

> *Shape seems to influence weight. The regular shape of simple geometrical figures makes them look heavier. This effect can be observed in abstract paintings, notably some Kandinsky's works, in which circles or squares provide remarkably strong accents within compositions of less definable shapes. Compactness—that is, the degree to which mass is concentrated around its center—also seems to produce weight.*

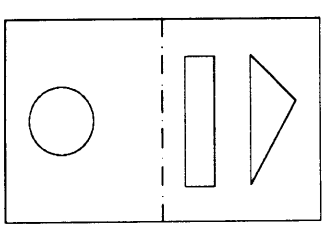


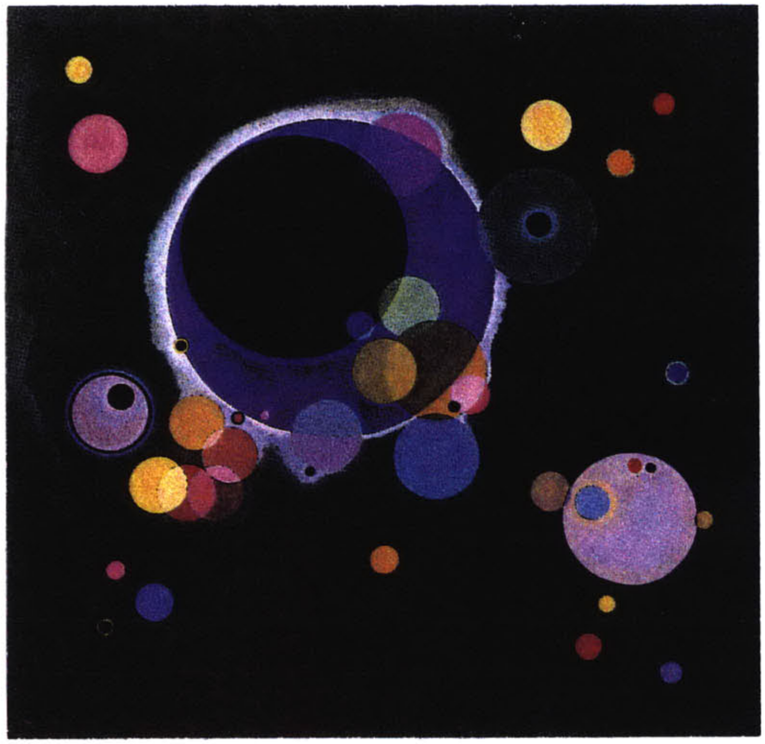
Fig. 7.33
The influence of compactness on the perception of balance according to Arnheim

I think that is the peculiarity of a certain shape among other shapes that gives it an increased weight, and not the fact that a certain shape has a simple geometry. He gives an example to illustrate the influence of compactness on the perception of balance (Fig. 7.33), in which "a relatively small circle counterweights a larger rectangle and triangle." However, the greater weight of the circle can be explained in terms of its larger distance from the center. In these circumstances, both the influence of isolation and shape, can be seen as affecting the intrinsic interest of an element in a composition.

We believe that further research can find a way to express the intrinsic interest of a certain element, or group of elements, in a given composition, be it caused by the peculiarity of their shape, their size, or their location, by measuring the degree of deviation of the values of their attributes from the average values of the same attributes for all the elements in the composition. To encode the intrinsic interest of a scene in a non-abstract composition seems, however, more complicated. We also accept that direction, especially in a non-abstract composition, might also be important. However, we will not address these two issues in this study.

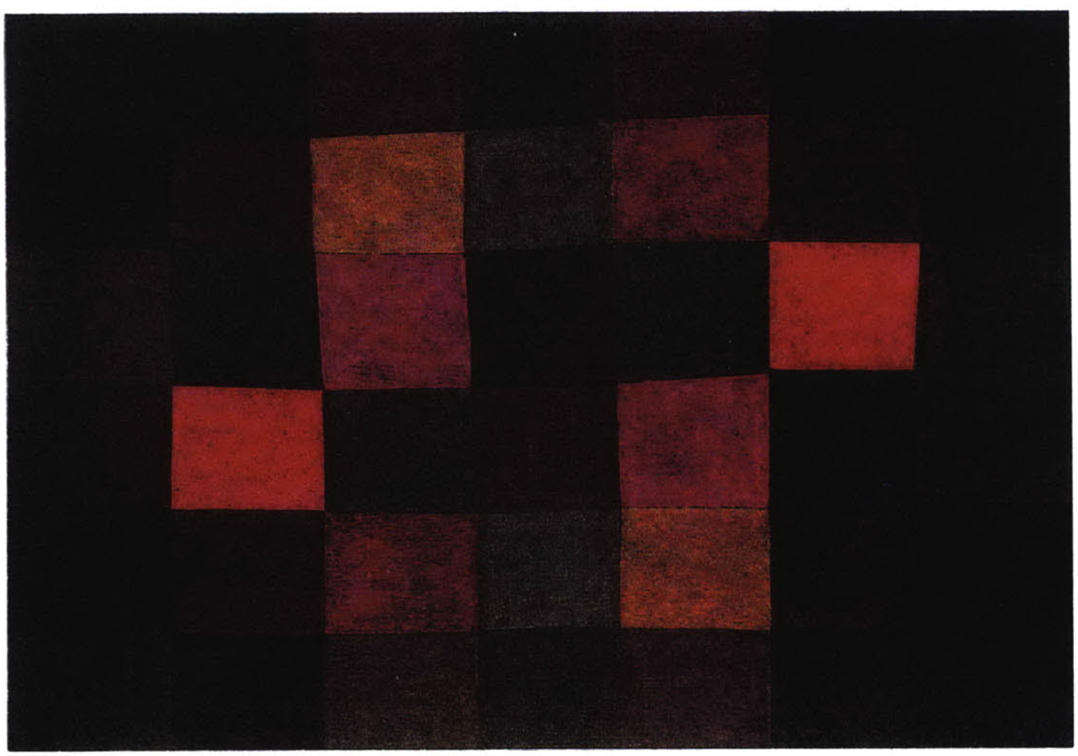
However, the remarks made require us to frame the precise context in which the mathematical model proposed is valid. The model explains accurately how the attributes of shapes in a given composition, such as color, size, and location, under medium conditions of lighting, influences the perception of visual balance in that composition by an observer. The model does not explain the influence of attributes related to the observer's cultural background such as the intrinsic interest of a shape, or a group of shapes. Nevertheless, the model incorporates some degree of subjectivity, by assuming the existence of reference axes upon which depends the perception of balnce. Two of those axes likely used by a common observer were proposed. These features make the model especially suited to abstract compositions, although it might also be applied to non-abstract ones as we shall see in Section 7.2.19.

Fig. 7.34
Compositions in which the concern for balance and the influence of a shape's area, position, and color on the perception of its visual weight are evident



Vasily Kandinsky, Several Circles, 1926
Note how the weight of the larger black and blue circles on the left, are counter- balanced by the numerous group of small and brighter circles on the right

Paul Klee, New Harmony, 1936
In this Klee's painting is evident the strive for counter-balancing each shape in the composition with a similar shape in a symmetrical position



7.1.12 Summary of the discussion of the "Spoken Game with Abstract Elements"

Memory constrains the way design activities evolve. Due to memory constraints, evaluation rules are more direct than generation rules. Moreover, designers need to freeze variables during the design and evaluation processes.

Due to memory constraints, designers simplify reality and are biased in this process. Designers' simplification of reality prevents them from achieving complexity in designing.

Different designers interpret the same design problem in different ways and so, use different design and evaluation rules in order to solve the problem. Because designers use different generation and evaluation rules in their design processes, they generate different design solutions. Therefore, Designers' different interpretations of the same problem generates the potential to create diversity.

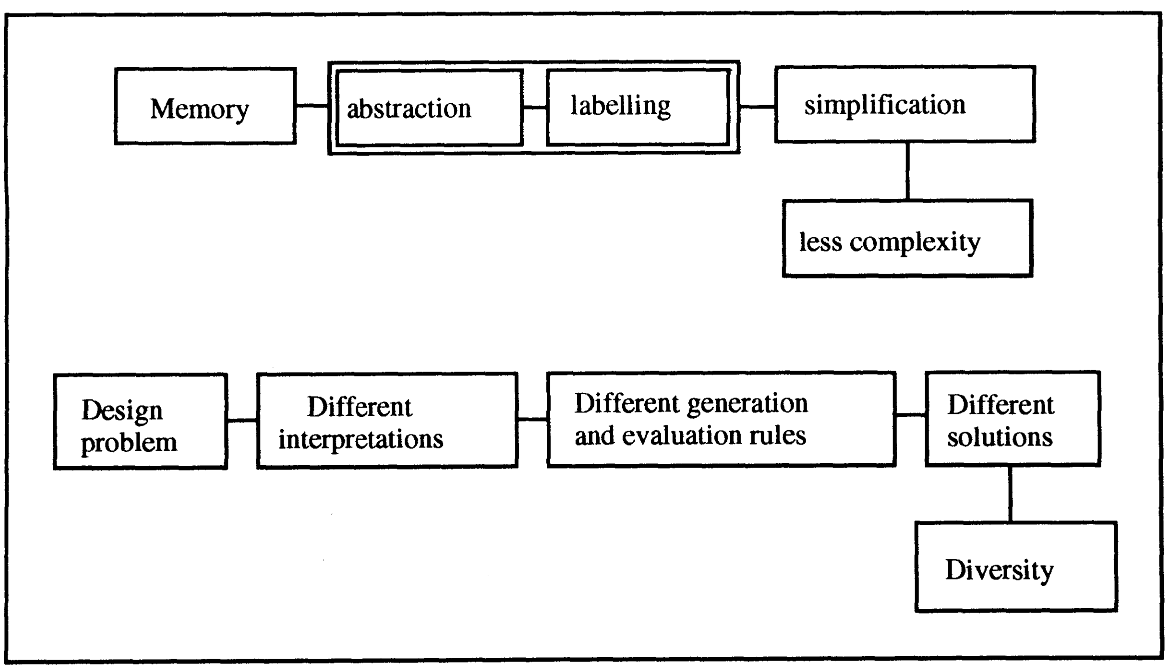


Fig. 36

When asked to generate diverse designs designers also express a concern for order seen, it seems, as a positive feature. The results of the experiment suggest that the sense of order is connected, among other things, to the perception of balance, and reveal the existence of horizontal and vertical balance.

The perception of horizontal balance is influenced by the area and position of shapes that form the framework of a composition, whereas the perception of vertical balance is influenced by the size, color, and location of all the shapes in the composition, as well as by the color of its background. The need to achieve diversity prevents designers from generating clearly symmetrical designs, and makes more difficult the achievement of balance since it requires designers to look at the shapes in the composition and judge them in terms of color, size and location .

An analogy with music according to which horizontal balance is compared to tonality, enables the development of a mathematical model for horizontal balance that describes Thomas' design process from this viewpoint. In this analogy, the height of the horizontal boundaries of the shapes that constitute the group of elements in horizontal balance are compared to different pitches in a musical scale, and their average height to the central tone around which the composition evolves. The formula used to calculate the average height is thus proposed as the formula for compositional horizontal balance. I raise the hypothesis that the model developed on Thomas' design process describes our own perception of horiontal balance in other compositions.

The use of a metaphor, according to which compositional vertical balance is translated into a question of gravity balance, allows the use mathematical functions to encode the rules that simulates the ones that Thomas used during his design process. In this model, colors are translated into a gray scale in which darker grays are heavier, and lighter ones lighter. Each gray tone is assigned a coefficient that measures its visual weight. This coefficient, together with area and distance, is then applied to a variation of Newton's gravity formula, proposed as formula for compositional vertical balance. . I argue that the model simulates our own perception of horizontal balance in his and other compositions.

In section 7.2.16, I will show how the two proposed models successfully describe the subjects behavior in the "Spoken Game with Architectural Elements."

7.2 'The Spoken Game with Architectural Elements' (Experiment B)

By bringing this study closer to an architectural setting experiment B should test not only the conclusions of the experiment A, with abstract elements, but also clarify the following issues. First, it should elucidate why design systems similar to the one used in this experiment are used by so few designers. Second, it should provide evidence that a building system is able to generate diversity but designers themselves restrict that potential. Third, it should clarify what factors lie behind this restriction, and how they differ from those involving abstract elements. Fourth, it should demonstrate how the computer could play a role in overcoming such difficulties. Fifth, it should elucidate the factors that affect the perception of diversity, and how that information could be taken into account to generate diverse housing facades, and to develop of a supportive computer program. Finally, it should test the validity of the mathematical models proposed for visual balance based on the results of the experiment with abstract elements.

Table B.I (Appendix B) records the experiments undertaken and introduces the subjects. Of the eight subjects Thomas, June, Wade, Taylor, Salvatore and Ming were actually designers, whereas Pedro and Ana were non-designers. Each experiment took between 80" and 113" (Table B.II). The term 'subjects' will be used from now on to refer to the group of people who participated in the experiments, whereas the terms 'designers' and 'non-designers' will be used to point out the category to which a specific subject belongs.

7.2.1 The influence of the experimental setting on the results

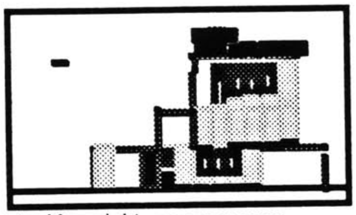
Five features of the experimental setting had influence on the way the experiment evolved

Five features of the experimental setting had influence on the way the experiment evolved: (1) time constraints from the designers who participated in the experiments, (2) the difficulty of placing accurately the elements used, (3) constraints created by the computer's slowness, (4) the difficulty of assigning the right architectural meaning to the shapes on the screen, and (5) the necessity of following a certain procedure. Nevertheless, these factors did not damage the experimental results, instead they contributed to simulate a realistic design environment.

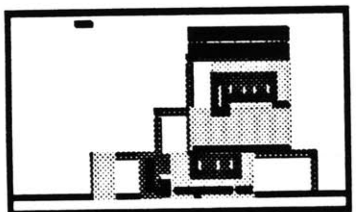
The subjects' time constraints

The set of experiments was undertaken at the end of the Fall semester, when students have little time available, and are busy with final papers. In order to decrease the time that subjects spent in I allowed them to finish the design with copy and paste commands once their moves were reduced to the placement of identical shapes. As a result between 0 and 33% of the moves were done without the 'Design Tracer.' (table B.V) Nevertheless, of that limited group between 70 and 100% were moves to 'select and place' new elements (table B.VII), or to put aside elements rejected with the 'Design Tracer' (graphic protocol, appendix B.1). Moreover, the most part of the new elements added were identical. The only exception to this scenario was June's design, in which only 39% of the moves without the Design Tracer were moves to place new elements. In fact, June's design was not close to be finished when the experiment had to be interrupted. I'll take this into account during the discussion of the results. Therefore, time constraints did not affect the collection and interpretation of the experimental data. They might have affected the design process, but they also affect any design process. In this sense, the experimental environment was realistic.

The difficulty of placing accurately the elements provided



1 - After eighty seven moves



2 - After finishing and correction

Fig. 7.36
The difficulty of placing accurately the system's elements obliged the subjects to correct their designs after the Design Tracer stopped

Because the catalog of elements provided included very small elements, the grid used to constrain the placement of all the elements also had to be very small. Therefore, it was difficult for the subjects[1] to place the elements accurately on the place they intended. So, between 2 and 20% of the total number of moves with the design tracer were to correct these misplacements (Table B.VI), and only between 80 and 98% were 'effective' moves. In order to avoid an excessive preoccupation with this inaccuracy, I informed the subjects that the misplacements could be corrected after they finished the design. Nevertheless, some subjects were more 'rigorous' than others, and took more cared in correcting these misplacements. Future improvements of the design tracer may include different grids for different groups of elements that can be activated whenever one element of the group is selected. In an object-oriented programming environment, this is able to be implemented and it will prevent the undesired effect.

The slowness of the computer environment

I have already mentioned that slowness prevented the simultaneous use of the 'Design Tracer,' the program for tracing the design process, and 'Timbuktu,' the software for screen sharing. Although the use of 'Timbuktu' was abandoned, some slowness persisted. This affected, of course, the way the design processes evolved since designers only made between 1 and 1.4 moves per minute (Table B.III). Because of slowness, designers avoided, in some extent, to change the design often. Only 0% to 16% of the 'effective' moves were moves that reflected change or hesitation (Table B.VII). Nevertheless, changes or hesitations occurred and the analyses of the different design processes confirm that subjects made changes everytime these were fundamental to reaching any meaningful design

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[1] From now on I will use the words designer or designers between quotes whenever it applies to all the people that participated in the experiments, disregarding if they were designers or non-designers. I will not use the quotes if the term only applies to the designers (graduate students of architecture).

result. See, for instance Salvatore's (Fig. B.6, moves 29 to 35) or Taylor's design processes (Fig. B.5, move 92, or 150). On the other hand, they had time to think while the 'Design Tracer' was running, therefore, their moves were not as spontaneous as they would be if it were faster. Nevertheless, as their speech was being recorded, part of this design thinking was captured. However, the fact that the Design Tracer slowed down the process counter-balanced the effect of time constraints, since it prevented designers from solving the design problem too quickly.

Iconic value of the elements provided

The colors and the hatches of the shapes were selected in order to suggest, as much as possible, the building components they were intended to represent. Therefore, the hope was that they would posses some iconic value. Nevertheless, the experiment showed that despite the initial additional explanation about the meaning of each shape, the icons suggested materials or even components different from what they were intended to represent. For instance, Ana saw the red-brick panels as wooden panels and that influenced her design. This should not be considered a negative effect of the experimental setting, since any kind of design media has similar effects. In fact, it should help to clarify the influence of the design media on the design process.

The system's procedure

The experimental setting required subjects to follow a certain procedure, since any element placed on the top of an existing element would appear imposed on that element. Therefore, they should place the structural elements before the wall panels, the wall panels before the windows and the doors, the windows before the mullions, and so forth. Nevertheless, this should not be considered a disadvantage, since it is common to other design systems or methods, and I intended to study how designers react to methodologies or procedures dictated by design methods.

The experimental setting constituted a successful simulation of a design environment

In conclusion, the experimental setting influenced the experiments, but not in a negative way or beyond a point which would invalidate the results. In fact, it constituted a successful simulation of a design environment.

7.2.2 Design Worlds

The system *failed*

The design world defined by the set of elements provided did not match the subjects' design worlds

> *Just as an assertion in critical language consists of verbal tokens (words) forming a one-dimensional string (a sentence), so a model is a collection of graphic tokens, such as points, lines, and polygons, forming a two-dimensional or three-dimensional arrangement. We can think of the space populated by these tokens, for example a drawing surface, or a three dimensional Cartesian coordinate system, as a specialized delimited micro world —the design world. (Mitchell 1990)*

> *From the very first moment of a design process, the designer deals with a situation. If he is an architect, he's given a site and a program. [...] From the very beginning, the designer perceives, appreciates and describes the situation. He makes initial sense of it. He notices some things and ignore others. [...] And he brings with him a repertoire of ideas, images, precedents, values, expectations and types -- some, particular to his identity as an architect; others, particular to the culture of which he is a member. Through this interaction between what he perceives and appreciates in the situation, he establishes an initial coherence. In effect he constructs a world in which to design, a world of his own making; and it is this world that he captures, more or less fully and accurately, in his initial descriptions of the situation. (Schõn 1986)*

As pointed out in the discussion undertaken in Section 3, any specific building system defined by a coordinated set of building components pre-solves some design problems in a systematic way, but it is not universal. The experiments showed, as expected, that the elements provided could not generate some design solutions imagined by the subjects. For instance, almost all the subjects, complained that they could not have cantilevers. Wade said:

> *W: (...) Once again we have to support the end of these columns... beams. It is frustrating to tell a person who likes cantilevers that he cannot have cantilevers.*

Taylor justified his preference for cantilevers:

> *J: You cannot have cantilevers.*
>
> *T: Why not? I...) Can I put these connective elements at the mid beam?*
>
> *J: No.*
>
> *T: Just at the ends. There were somethings that I would change now, if I had the freedom, but I don't.*
>
> *J: What would you change?*
>
> *T: I would reverse these two. So that they could come and intersect this level up here. I like cantilevers.*
>
> *J: Why?*
>
> *T: Because it is easier to create outdoor spaces.*

Pedro, a non-designer, also complained that he could not have a sloping wall:

> *P: (...)I would like to draw a sloping wall. If I were (hand)drawing, that is what I would do. Anyway, I like this like it is. Can I put a verandah.? A cantilevered verandah. That is what I would like to have: a verandah, and a sloping wall.*

Therefore, there was a gap between the design world defined by the system, and the subjects' own design world. They overcame the situation by simply restricting their design world to what was possible in the system. Ana was the only subject who did not have a problem with cantilevers, because in the design world where she was operating, there were no cantilevers. Nevertheless, her design world also did not correspond to the system's design world.

> *A: (...)And now a window. I am going to make it fancier. No...In this I am going to put some decoration, but later... I think that my Beacon St. is going to change to a fishermen's neighborhood.*

However, when she saw that the system did not provide the means to reproduce the decoration level of her initial paradigm, Back Bay, she shifted the paradigm. It was easier for her to bridge the gap than for the other subjects. For them, the

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However, when she saw that the system did not provide the means to reproduce the decoration level of her initial paradigm, Back Bay, she shifted the paradigm. It was easier for her to bridge the gap than for the other subjects. For them, the gap cause them to go through a convoluted design process in order to express their initial ideas in the system's design world or to make some of their initial intentions come through. Salvatore's design process (Figs. B.6, and 7.37) is a good sample in this respect. First he tried to develop his design following his intentions, but when he saw that it was not feasible, he destroyed part of his design (moves 29 -31). Then, he tried to use different elements to make it possible (moves 32 and 33,). When this did not work either, he changed his idea.

> *J: So, did you change your initial intentions?*
>
> *S: Yes. Almost totally.*
>
> *J: Why?*
>
> *S: Because there are not enough elements for it, to do what I want to do. So, I just changed the composition of the elements.*

At the end, when he was explaining his rule, he clarified:

> *S: (...) And then there was the problem that the pergola couldn't fit the space, and I came up with the idea to*

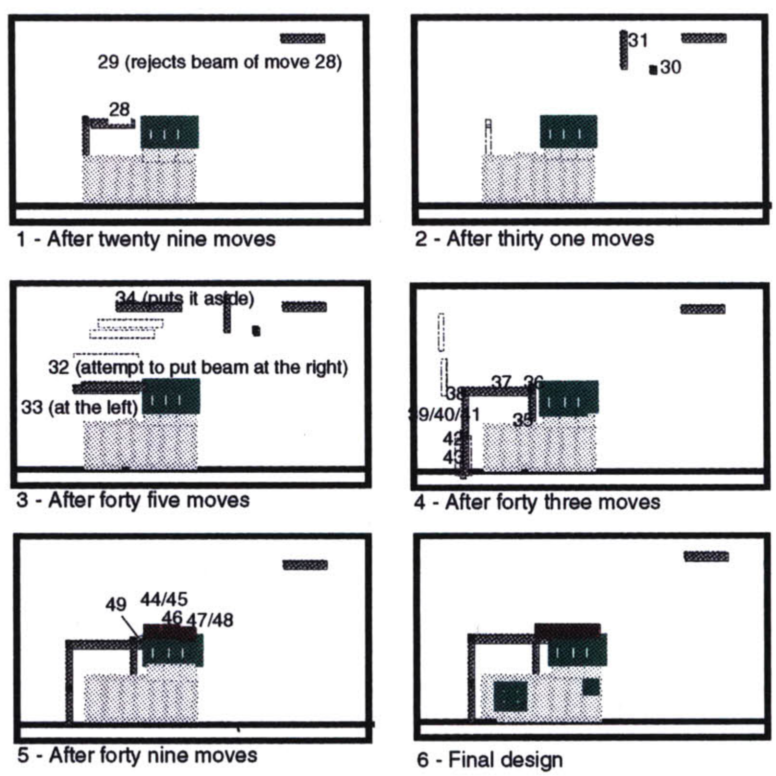


Fig. 7.37
Salvatore's design process (moves 28 through 49)
There was a gap between Salvatore's design world, and the system's design world that constrained the development of his design process

move everything out, and to put the entrance in the back. So, to transform this facade in something, not in the main facade, main elevation on the street, but a kind of a lateral elevation, switching the meaning of the relation between, the elevation, the main elevation ,with the building and the street .

Therefore, Salvatore had to change the functional meaning of his design. Nevertheless, he kept his compositional idea of deconstructing a large volume revealing the structure.. Moreover, in the moves that followed the partial destruction of his design, Salvatore tried to come as close to his initial idea as possible . Move 49 is very meaningful in this respect. By placing the beam that connected the portico and the body of the house, he made more evident the reading of the drawing that was in accordance with his idea.

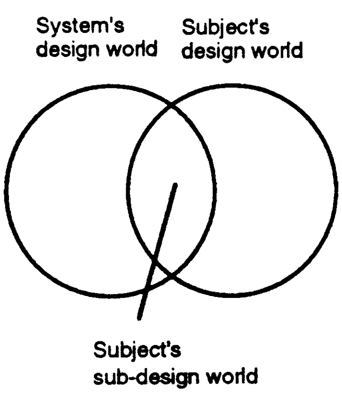
In conclusion, the gap between a system's design world and designers' design worlds requires them to abandon their initial intentions, by shifting their design paradigms, or restricting their own design world (Fig. 7.38) in order to operate within the system.

As an alternative, they may also be more inventive in order to express their ideas in the design world defined by the system. However, even when they succeed in overcoming the limitations, they feel a lot of dissatisfaction and frustration. Salvatore said:

J: Why aren't you happy about it?

S: Because there aren't really enough elements. A problem with size and everything.

Hence, not only does the gap between design worlds make the design process more difficult, but it also makes designing more frustrating. These two hurdles are enough to discourage designers to use of a specific system based on a set of standard components. Here might rest the explanation why these systems are scarcely used by designers beyond those who developed them.



7.38
The systems design world did not match a subjects' design world who, in order to operate within the system, restricted his design world

7.2.3 Design procedures

The system *failed*

The system's procedure did not correspond to the subjects' procedures which were not direct due to memory and appraisal constraints

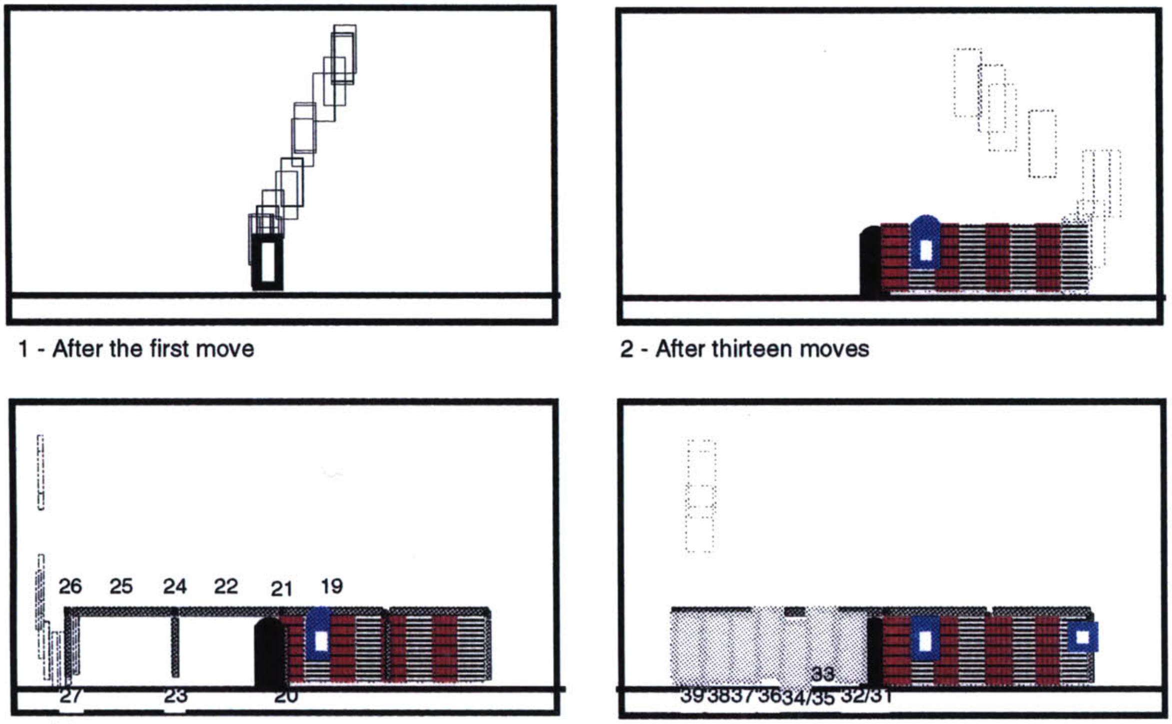
> *Although design is basically a "human process by definition, it is necessary to differentiate it from 'machine' design, or computer aided design, and design methods, or rational design tools for human designers. As opposed to these, the kind of design that is the topic of this study has been called intuitive-design in the past. [...] It is necessary to understand intuitive-design to predict the performance criteria useful in developing appropriate tools for machine-design or design-methods. In the past, the biggest road-block for the wide-spread use of design tools in the architectural offices has been the incompatibility of these non-intuitive tools with those of intuitive design. [Akin, 1990]*

The procedure required by the system used in the experiments did not match the subjects' procedures. The system required designers to build the structural frame, then the wall panels, then the windows, and finally build the roof or subdivide the windows. Since any element placed later on the top of an existing one would appear superimposed on that element, any failure to follow this procedure would result in undesired effects, such as windows hidden by panels, or beams resting on the top of panels. The system's procedure was illustrated only at the beginning of the experiment (see section 4) and the subjects sometimes disregarded it. For instance Pedro, a non-designer, noticed right from the beginning:

> *P: I should start with the beams. The design will be constrained by the things that you have here. If I were drawing freehand I wouldn't follow the same sequence. Can I start with the non-structural elements and put them in later?*
>
> *J: You decide that.*
>
> *P: So, I can place a wall and place the window on the wall? But, how am I going to place a beam, for instance? Can I place it on the wall, even if in reality it would be behind it? Let me start with the door.*

Although he was aware that the system did require a specific procedure, and he had some hints about what it could be, he did not follow it. Instead, he put the door first, and moved on to the wall panels. Later he noticed:

> *P: I am going to put in a column. The column is shorter. Now, I need a beam. I have to place the connector.*



1 - After the first move

2 - After thirteen moves

3 - After twenty seven moves

4 - After thirty nine moves

Fig. 7.38
Pedro's design process
(moves 1 through 39)
There was a conflict between Pedro's and the system's procedure

I've just built the right side of the ground floor. Now, I am placing the beam to start the second floor. I haven't decided yet, what I am going to do;-- the second floor, the left side of the house? How am I going to place the beam? I don't want the beam to be seen. Can I put a panel on the beam later? Now, I have to put a column but... The column is going to be placed on the panel. So I will have to put another panel later to hide the beam. Oh, I see, I should have started with the beams. The architects start with the beams. You could have told me to start with the beams. Yes, that's true that in the building works they start with the columns and the beams. But in drawing, it doesn't have to be necessarily like that. We are freer. [...]This time I will start with the beams and I will place the walls later. I am starting with beams to avoid overlapping. [...]The windows will be the last thing. Because I want to see other things. I am learning the essential about architecture -- to put the columns and the beams. first But I think that the architects worry about aesthetics first and don't worry about the beams and the columns. Only at the end they try to find a way to place the columns.

Therefore, not only was Pedro's natural way of designing different from the system's procedure, but also, as he, himself, pointed out, designing is different from building. In construction, one has to build the structure first or in order to avoid collapse, or one has to plaster the walls before carpeting the floor, in order to avoid dirtying it, as the building grows. But how could we characterize the logic behind designing'? Taylor, a designer, also had trouble following the system's design procedure:

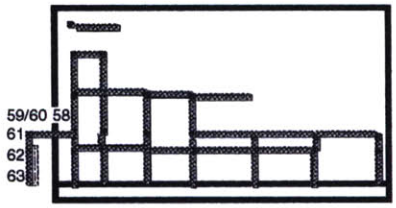
> *T: [...] It's time for the cladding now. What ever I will put on last, will overlap what is already in, right? I mean, if I want to put a window down here, I can't put it in before I will have the cladding on.*
>
> *J: Why do you want to put the window now?*
>
> *T: Because I have this theory that ...first what you can do is to put down what you know and it helps to inform the rest of it. And the problem is I don't want the cladding to overlap it.*
>
> *J: You can put the window again later.*
>
> *T: I will try just to put the cladding on.*

Wade, another designer, exhibited a similar concern, but unlike Taylor he proceeded with his idea of indicating the window areas at an early stage of the design process. He said:

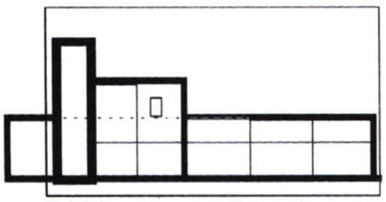
> *W: So, I am using these white panels now, to articulate the entrance. [...] I'll use the large panel to define the door.*
>
> *J: But you haven't doors now.*
>
> *W: Yes, right. But I will have to put the panel before the door. So, I'll use a large panel to define the door area. Now it falls... the part window area. Yes, use the large panel for both the window and the door just doesn't seem right. So, again, I am using this small white panels for the zones that can be particularly used to open windows.*

And he also said that:

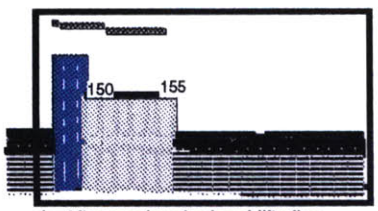
> *W: Once again we have to support the end of these columns... beams. It is frustrating to tell a person who likes cantilevers that he cannot have cantilevers. Let's support the floor... step this space down, or step this space up. Are this two connectors here plus these two columns here equal to the entire height of one of these columns. I guess one of the longest columns is equal to the height of a connector, plus two of the medium size...I don't know what I want. I am just trying to finish this...perhaps, instead of figuring out what to do, I'll just do something and see what then it makes me think of. When you are puzzled it is better to do something and just stop thinking.*



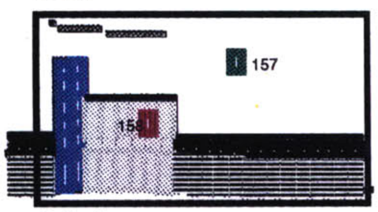
1 - After sixty three moves



[...] If I want to put a window down here, I can't put it before I will have the cladding on' (Verbal Protocol).

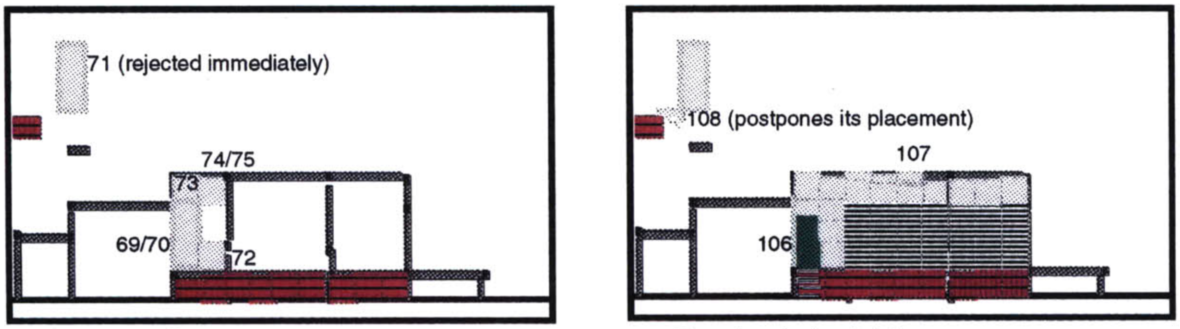


4 - After one hundred and fifty five moves



3 - Last move

Fig. 7.39
Taylor's design process (partial)
The systems procedure constrained Taylor's design process



1 - After seventy five moves

16 - After a hundred and eight moves

Fig. 7. 40
Wade's design process
(after seventy five moves)

Both Taylor's and Wade's behavior suggest that in designing, one needs to lay down what one knows about the design in order to record ideas, to assess the corresponding state of the design, thus informing the rest of the design process. If it were possible for designers to build internal descriptions of all the possible design states and asses them, they would not need to build any external description. Therefore, either they do not have the memory required to build those internal descriptions, or the ability to assess them, or both, as we have already found in 'The Spoken Game with Abstract Elements.' These results suggest that the natural way of designing is not direct due to memory and appraisal constraints.

Ana's design process is another good example of that phenomenon. Her design process is diagrammed in Fig. 7.42, and represented in more detail in Fig. B.9 (Appendix B). Unlike

Fig. 7. 41
Ana's design: a street facade

Diagram of Ana's Design Process

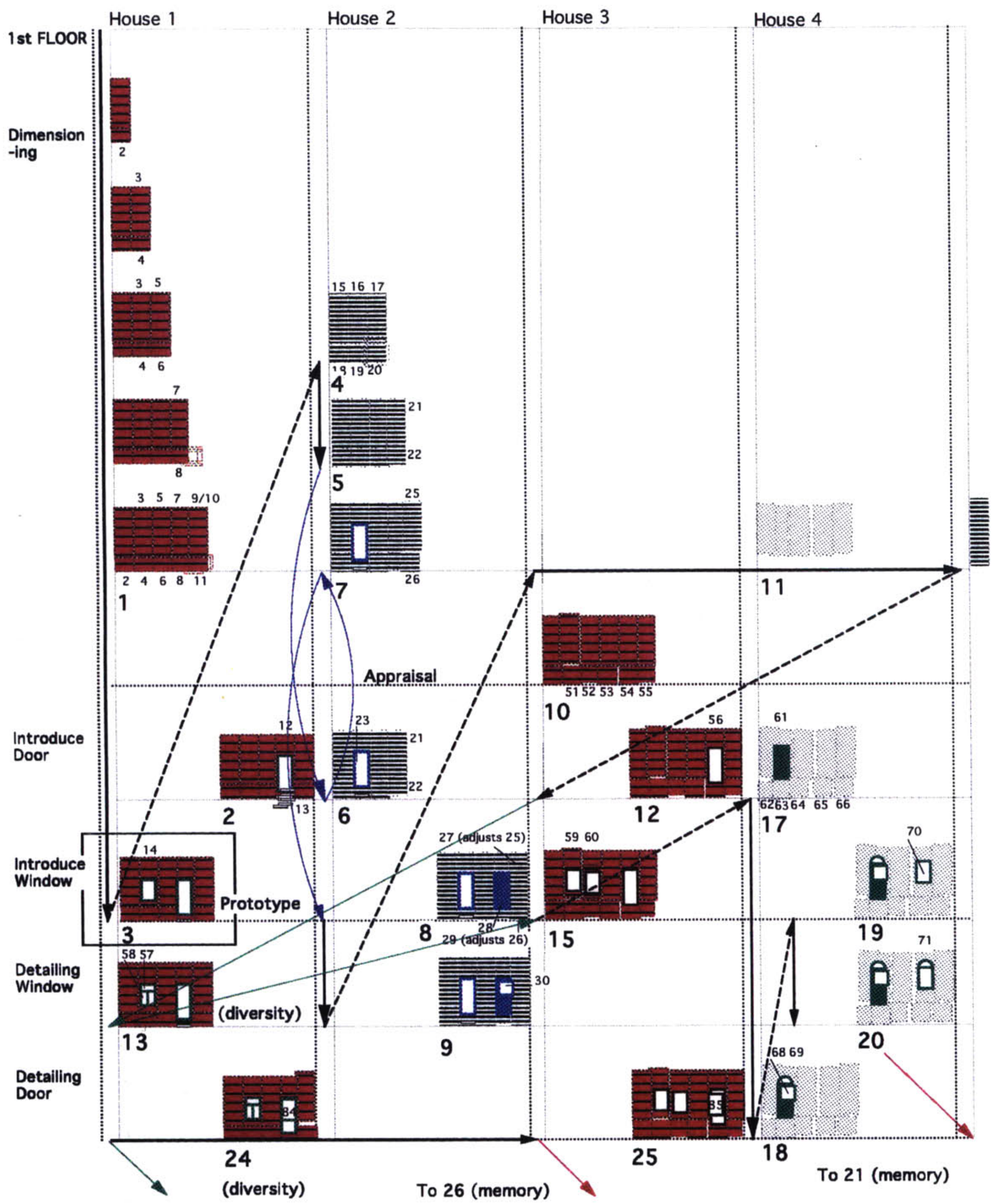


Fig. 7.42
Diagram of Ana's design process

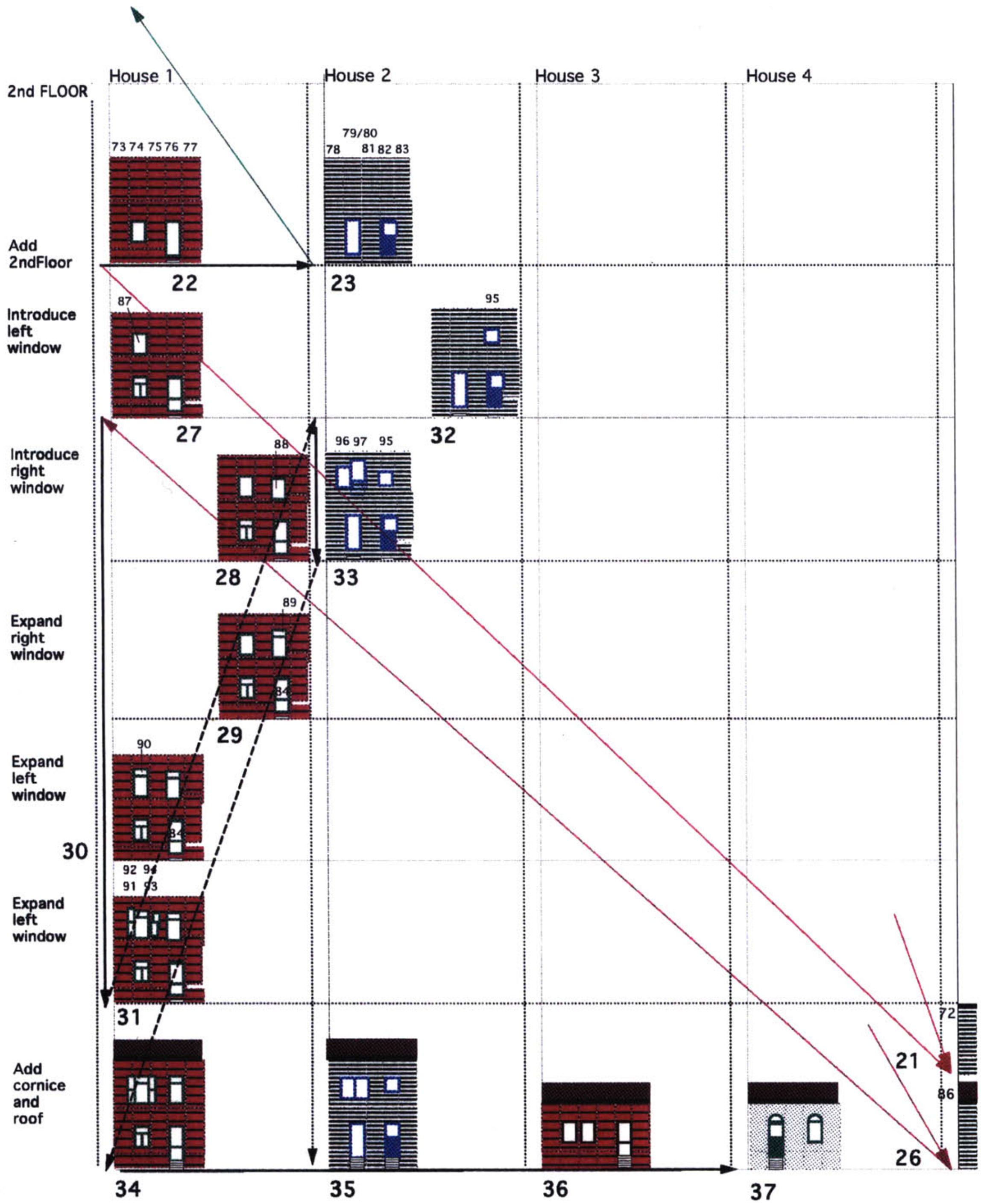
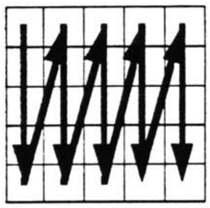


Fig. 7.42
Diagram of Ana's design process

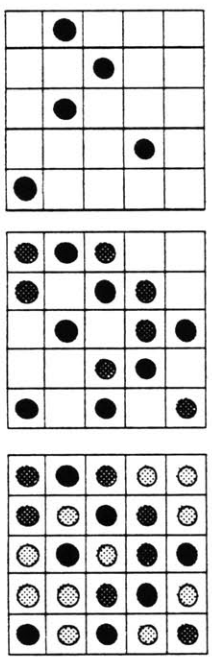
the rest of the designers, Ana built several houses in a row (fig. 7.41). However, she did not build one house all at once, and then move on to build the next one, and so forth. Neither did shebuild all the wall panels, then all the doors, and then all the windows. She did not follow any straightforward process based on type, color, shape, or any other similar criterion, but used a combination of all, interrupted frequently by shifts in process. She first defined schematically her first house that became her prototype, and then moved on and defined the second house, and established the number and sizes of the remaining houses.

Direct processes



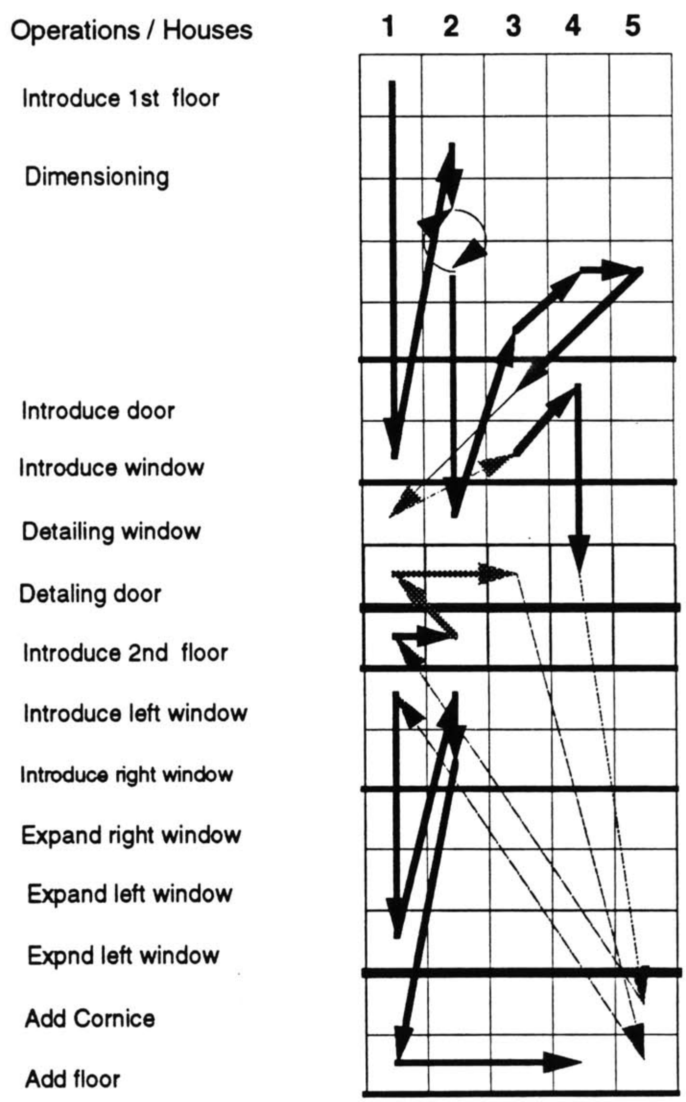
a - By column

b - By Row



c - By Color

Non-direct process



d - Ana's design process

Fig. 7.43
A comparison between the diagram the diagrams a b c, and diagram d that is a synthesis of Ana's design process shows how non-direct her process was. In the diagrams columns represent houses, and rows represent design operations

Then she moved back and forth from house to house until she built the roof of all the houses and then finished her design process. If we compare Ana's design process synthesized in Fig. 7.43 with diagrams a,b, and c in the same figure, we see how distant from any direct approach was Ana's design process.

A close analysis of Ana's design process diagrammed in Fig. 7.42 revealed that the shifts in her design marked in thin-lines, were due to appraisal and memory constraints, or to the need to increase the detail of the houses in order to increase the degree of diversity of the design. A good example of moves prompted by appraisal constraints are moves fifteen through twenty six. As explained above Ana first defined her prototype that consisted of a house made of five wall panels, a door and a window. When she moved on to the next house, she tried to make it different. First she built a wall with three wall panels, but she rejected it because it could have no window, without disrespecting her rule, "I cannot place a door (or a window) on the first panel of a house." Then she increased the size of the house to four panels, and moved on and placed the door. After her assessment, she concluded that 'the windows cannot be attached to the door.' Finally, she moved back and increased the size of the house to six wall panels. In conclusion, Ana did not follow a systematic procedure because she needed to depict intermediate states of the design process in order to asses them.

On the other hand, Moves 72 and 86 are good examples of how designer's memory structure constrains the design process. Ana had just finished detailing the fourth house when she decided to place a cornice on the fifth house, just to remind her of her decision.

> *Let's put the cornice. I will put only one, but in fact I want them in all the buildings. I will do the same with the roofs, you will know. Well, there are three panels and five windows missing. The windows shouldn't have an unique big glass. I think it should be divided. I have to divide the doors. They can't have such a big glass. Children could break it.*

Then she moved and built the second floor of the first two houses. Then she decided that the windows could not have a unique glass, and that reminded her that the should not have a big glass on the doors either. So, she divided the glasses of the doors into smaller glasses. Once, she finished this task she went back to the fifth house and placed a roof element before she continued to work on the second floors of the first houses. Interestingly enough, Ana moved from part to part of her design guided by associations established by her memory. When she finished completely one house she remembered the need to place the cornice. Because she had to place and divide the windows to make them different from other windows in the drawing, she was reminded of the necessity to divide the glass of the doors. On the other hand, because she wanted to free her memory from the need to place a roof element, she placed the roof element before continuing to detail the windows. Therefore, Ana's design process demonstrates that memory is major factor and affects the way the design process evolves, either by association, or by its limited capacity.

Additionally, designers do not manipulate specific elements during their design processes, but rather, manipulated abstract entities, that are progressively defined as the design evolves. For instance, Taylor also pointed out:

> *I like the blue. I really wish I could just draw a box where I want my window instead... I mean, I knew this all thing about elements that I am filling... [but] I wish I could just bump a window here, bump, bump, two more windows, then I can have what ever size that I want, that's not the idea, so... It [my window] wouldn't be necessarily one of the shapes that you gave me.*

In other words, although he knew that he wanted a window at a specific location he might not have known exactly which window, that is, which shape, size and color, and there was a possibility that he could choose none of the windows provided by the system. Therefore, the 'modules' that he manipulated at early stages of the design process were more abstract than those provided by the system. These abstract modules are, in fact, types. When a system provides defined elements, it forces designers to invert the normal course of their design processes. Furthermore, the design loses flexibility which can compromise a solution when several defined parts of the system contradict each other. Therefore, because designers use types during the design processes not only do they maintain the flexibility of the design , but also they manipulate a lesser amount of data, which reinforces the idea that memory plays an important role in the design process.

In conclusion, there was a gap between designers' designing procedures and that of the system. The results also suggested that a *rationalized* procedure of a design system that contradicts designer's *intuitive* way of designing, which is driven by memory and appraisal constraints, is likely to pose designers serious problems in its application, or even compromise solutions. This is true if the design system is informed by building considerations. The gap can be overcome by designers to some extent, but it requires additional time and learning efforts. These considerations help us to understand why design systems such as the SAR method, have been used by so few designers.

7.2.4 Designers did not create diverse designs

Designers *failed*

In their own opinion, designers did not create diverse designs

Although the set of elements provided had limitations, namely it did not correspond to the designer's design world, it was able to generate diverse designs. However, each designer failed to achieve diversity in his/her own design. Therefore, designers failed to use the system effectively.

When I asked designers whether they considered their designs diverse they answered:

*T: **I completely forgot about diversity.** Well, it is repeating those things to a certain degree but [it] doesn't fill up the whole structure. And then there are two open [?] for the structure to be exposed once completed, and it's completely clad, and the upper one is not completely clad and the windows are different, but the same color, the same repetition, so you can find some diversity. (Thomas, 2nd design)*

*Jo: **Yes, compositionally.***
J: Compositionally? why?

Jo: Like a... street facade, shops, you enter at the ground level, and then we have windows here, there. And may be we'll have street courses. So, I was thinking that way. I don't know. And I was worried about to put all these pieces... on the facade, and not worry about the structure. Except where it would be exposed. (Joan)

W: In terms of diversity? Oh, god! I don't know. I mean... I certainly didn't try to make it uniform. I tried to keep some consistency in the application of objects and relationship to objects. So, I didn't try to use the objects... differently each time I used them. So, I didn't use diversity in that way. Probably a diversity more in... Oh! It's scary! (Wade)

*T: **It's no less diverse than that.***

J: What do you mean by that?

*T: I **claimed that this wasn't diverse**. I don't think it is particularly. I think... Yes, he used all the different pieces. This is diverse in terms of, 1, 2,3,..., 14 different elements or something, it's not as diverse as it could be, but I think it falls in the category of basically diverse. This is as diverse as that. This guy used some chaotic window type to try to create diversity. I think it is a poor excuse for diversity. I have diversity here, in terms of, I am showing structure, I am showing glazing, I am showing panels, I am showing cornice, and I have different colors of windows, and different sizes of windows,...I have different sizes of panels, to some extent... **I understand, I take your criticism.** (Taylor)*

*S: **You didn't tell me that it should be diverse!** You told me to design a facade with these elements. You told me that it should be diverse? I've just listened that I should design a facade. Anyway, I did so that... If I had to defend my project (...). (Salvatore)*

M: Diverse in, in, not necessarily in elevation, but in level are changes that always express, for instance, I have very... very consistent open space, for instance, you enter into the house, so, there is always a space. It's the same language, but I think there is the diversity of the use. Of entrance, for instance, this becomes a balcony, this is the entrance, this is the terrace.

J: Do you consider the facade diverse?

*M: **The facade is not diverse.***

J: But I asked you to design facades diverse, a diverse facade.

M: I remember (Ming)

So, all the designers except Joan, acknowledged the lack of diversity of their designs.

7.2.5 Designers did not use all the elements and colors available

Designers *failed*

The analysis of the graphic protocol shows that designers did not use all the elements and colors available

Some of the subjects suggested that it was not possible to achieve diversity with the few set of elements provided but subjects did not use all the elements and colors available anyway. For instance, Salvatore said:

> *S: We are so much concentrated in the elements that we forget to think diverse. When you say: 'you have to design a facade with these elements ,' we just think (that) the elements are not so many. So ,we think: 'what can we do with these few elements?' My problem... And, psychologically, we refuse the issue of diversity...*

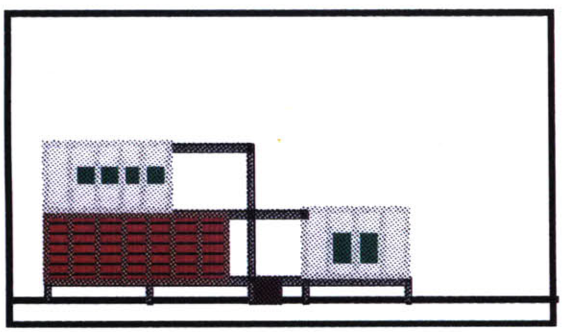
However, if we analyze Salvatore's design we discover that he used only 21% of the 62 different elements, and only 40% of the 10 colors/textures provided (Table B.VIII). Even June did not use all the elements and colors that the system provided; she used only 32% of the elements, and 70% of the colors. The behavior of the rest of the subjects also exhibit similar features. The designers manipulated between 15% to 58% of the total number of different elements available, but used only between 15% to 39%. Additionally, they hid some of the elements that they used. So, the number of visible elements in their designs was less than 32% of the total number of elements available. They also used only between 40% to 70% of the color-patterns available, despite manipulating between 40% to 80% of them. The non-designers' behavior was more consistent, but similar. They used the same number of elements they manipulated (26%), and there was only a slight variation between the number of elements used and the number of visible elements.

Nevertheless, the number of visible elements they used was similar to those of the designers (21%-26%). So, both designers and non-designers used significantly less visible elements than those provided by the system. Therefore, it was not merely a problem too few elements or colors.

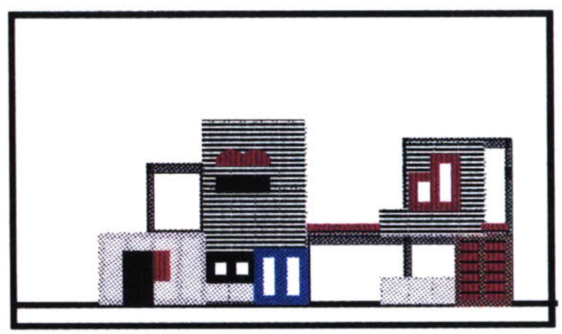
7.2.6 The total of all the designs was more diverse than each design

Designers failed

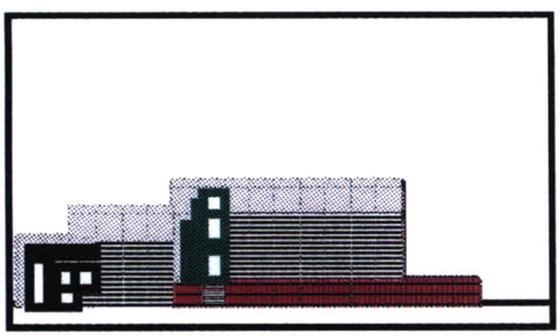
If we compare each designer's design with the set of all the designs (Fig. 7.44) we conclude that the system was able to generate more diversity than the one that each designer achieved in his/her own design.



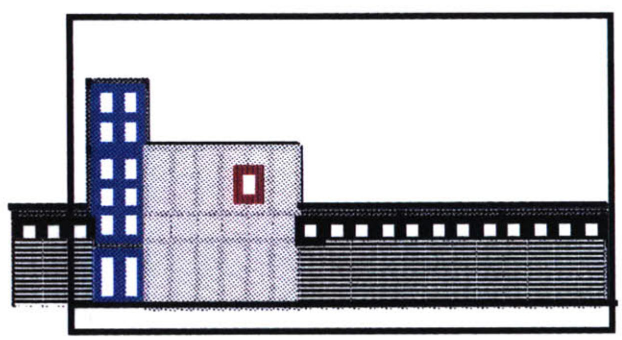
1- Thomas' design 2



2 - Joan's design

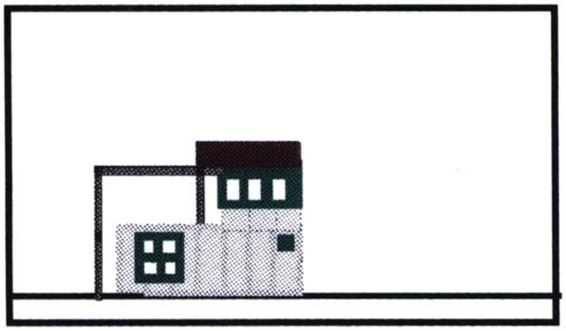


3 - Wade's design

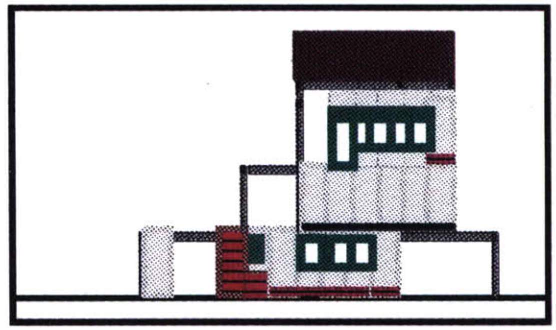


4 - Taylor's design (reply to Wade's)

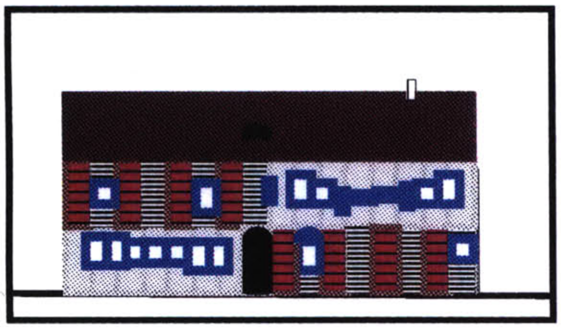
Fig. 7.44
The total of the designs was more diverse than each design



5 - Salvatore's design



6 - Ming's design (reply to Salvatore's)



7 - Pedro's design (non-designer)

8- Ana's design (non-designer)

Fig.7.44 (continued)
The total of the designs was more diverse than each design

The results suggest that a small set of standard building components can produce diversity but designers failed to use this potential

The discussion undertaken in the previous sections enable us to precise the argument of the discussion that follows. On one hand, we saw that the system had some limitations because the design world it defined and the procedure it required did not correspond to those of the subjects. I argued that these limitations explain why systems similar to that used in the experiment are used by so few designers. On another, we saw that designers failed to generate designs but they did not use as many different elements as they could have used. We also saw that the set of all the subjects' designs was more diverse than each individual design. Then, we have necessarily to conclude that the system's potential to create diversity was bigger than the degree of diversity that designers achieved in their designs. Therefore, the argument that the few elements provided were not enough to enable them to do a diverse design is not valid, and so we have to consider that a small set of components is able to generate diversity but designers failed to use this potential. The following sections aim at exploring the motifs behind the designer's failure, and at the same time, precising what are the factors that affect the perception of diversity.

7.2.7 The subjects restricted their design world

Why did the subjects *fail*?

1

Designers (and non-designers) only explored the design world defined by the intersection of his/her design world and a system's design world

We have seen that the system's design world did not match the designer's design world (section 7.2.2). Additionally, designers only explored the system's design possibilities to the extent that they overlapped their own design worlds. For instance, Pedro, one of the non-designers, categorically refused the holes. At an early stage of his design process he asked:

> *P: Are these two components of the window?*
>
> *J: No. That is just a hole.*
>
> *P: A hole? Why do I want a hole without a window? Do I have to place the hole and then the window?*
>
> *J: No. You don't have to.*

And at the end he insisted:

> *P: I don't understand this idea of the holes. A hole? For what? For a monument?*

Holes did not populate Pedro's design world, just as green windows were not a part of Joan's, a designer, although she did worry about using all the elements:

> *Jo: (...) And I was worried about putting all these pieces on the facade, and not worried about the structure. Except where it would be exposed. I didn't use the green. I didn't like the green... color.*
>
> *J: You didn't like the green color?*
>
> *Jo: No. Unnatural.*

Ana, the other non-designer did not like the red windows:

> *A: I've used all the window types. Except red windows, because I don't like them. I think they are too...*

The fact that she set aside the red windows is meaningful. Like Joan, Ana was concerned with using all the elements. She used all the possible colors and patterns that the system provided, except the red (windows) and gray (structural elements) (Table B.IX). She did not use the structural elements because she did not consider the hypothesis of having them visible:

> *A: (...)I am not going to put beams, anyway we wouldn't see them. I don't like... it is picturesque, but I prefer monumental.*

Furthermore, she also excluded some possible arrangements between elements:

> *A: Diversity has limits. In the same house I am not going to paint the windows with different colors.*

Other designers excluded other possibilities (Tables B.VIII and B.IX, and Verbal Protocol-Appendix B.3). In conclusion, the subjects did not explore all design possibilities provided by the system. They excluded either some of its shape tokens and shape attributes, or relationships between shape tokens and/or shape attributes. Additionally, different subjects excluded different design possibilities. This suggests that designers consider only those design possibilities that are included in their design worlds, and that different designers explore different sub-worlds (Fig. 7.45). *So, there is no point in developing design systems that are associated with a large design world and to expect one designer to use all possible design solutions, since he/she will never consider some of the solutions in the system. Furthermore, one designer does not achieve as much diversity as several designers.*

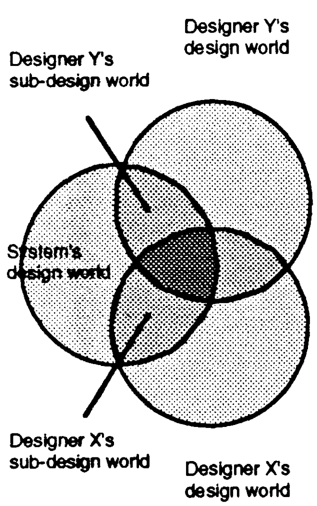


Fig. 7.45
Designers do not explore all the design world of a given system

7.2.8 Education

Why did designers fail?

2

Education prevented designers (and non-designers) from generating diverse designs

As pointed out in section 7.2.4, designers admitted that their designs were not diverse. However, when Pedro and Ana, both non-designers were asked whether they considered their designs diverse, they answered:

> *P: Diverse? Yes. Let's say that it is classic but non-orthodox. It is a combination between the traditional, the lines are rectangular, and the composition of colors and windows [which is non-orthodox], where there is a great diversity. And it is uncommon. (Pedro)*

> *A: I think it is enough diverse. The color of the facades, the color of the doors, the number of doors, the height, the type of windows. It were rigid, if it had obeyed a common structure, it would all be brick facades. All with a door to the street, a facade with a fixed height. For me, this is diverse. (Ana)*

A comparison and analysis of Pedro's and Ana's designs with the rest of the deigns also support their own opinions. First, non-designers used more color-patterns than any of the designers (Table B.VIII). Second, they did not try to hide the diversity they had achieved at the beginning of their designs as did the designers who used more different elements. There was no significant difference between the number of different elements they used, and the number of different elements visible in their designs (Table B.VIII). Therefore, non-designers had a more consistent behavior.

In conclusion, the difference in behavior between designers and non-designers can only lead to the conclusion that architectural education prevents designers from generating diverse designs.

One can argue that designers felt threaten when they were asked to design, whereas non-designers felt completely free to do whatever they wanted. Non-designers were asked to do something that fell out of their own areas of work, so they did not feel pressured to provide a "correct" solution. Nevertheless, this reinforces the idea that architectural education constrains designers when they are asked to create diverse designs. On the other hand, if one pays attention to how Pedro, a non-designer, described his design, 'classical but non-orthodox,' one has to conclude that not only architectural education constrains diversity, but also one's general education, is restrictive as well. If a design is non-orthodox because it is diverse, it means that an orthodox design (one that follows the canons established by education) is not diverse. In other words, if the features that lead to perceive a design as diverse, cause it to be judged as non-orthodox, then a design that does not have those features is orthodox and non-diverse. Therefore, educational canons and ultimately education, restrict diversity. Pedro had to be non-orthodox in order to create a design that he could perceive as diverse.

7.2.9 Toleration of diversity

Why did designers *fail*?

3

Designers only tolerated a certain degree of diversity

We saw in section 7.2.5 that subjects used fewer elements than those provided by the system . In this section we will see that subjects did not use more elements because they had a limited toleration for the diversity in their designs. Wade's process is paradigmatic in this respect. Wade was the subject who used more different elements and more different colors-patterns in his design, but he used only 70% of the colors, and only 39% of the elements available in his design, despite manipulating 58% of the elements. Moreover, the number of visible different elements was only 27% of the number available (Table B.VIII).

He started his design process trying to use as many different elements as possible. Since he decided to place the structure before anything else, he tried to create different structural bays, both in terms of span and height.

I am trying to get some type of structure that will let me have some sectional differences between the space *defined by this tall column and the extra long upper space, a sort of a clear story space.*

Later he forgot the issue of diversity, and he acknowledged that:

That's interesting. I have... I forgot about the diversity thing, but I certainly have diverse clear stories.

He seemed to be satisfied by his diverse structure, but after a while, he started to perceive it as too 'chaotic':

Oh (), I have to get some columns in here to support... I am not using the columns to... I mean, the columns are going to be for interior walls but obviously some of them are going to be in the wall, interior. This is an elevation. So, you won't be able to tell that.

So, when he clad the wall, the diversity he had achieved with the structure was rather restricted, and at the end he had completely forgotten the diversity requirement.

J: How do you judge it in terms of diversity?

W: In terms of diversity? Oh, god! I don't know. I mean... I certainly didn't try to make it uniform. I tried to keep some consistency in the application of objects and relationship to objects. So, I didn't try to use the objects... differently each time I used them. So, I didn't use diversity in that way. Probably a diversity more in... Oh! It's scary!

J: Do you consider it diverse?

W: Ahhh.... There is some diversity in level changes, in ceiling heights... I mean.. . there is variation. Diversity and variation are not exactly the same thing. I think it could be more diverse. I was thinking of it as being a little more ambiguous in the use of certain use of materials. But then, it might also be completely unreadable and ununderstandable.

So, Wade, manifested a limited toleration for the diversity in his design. The other subjects' design processes were not so evident as Wade's; they did not try as hard as Wade to use many elements but rather restricted the number of different colors and elements right from the beginning. Nevertheless, they also manifested a limit for the number of different elements and colors they could tolerate in their designs, as seen in section 7.2.5 and as the analysis of Table B.VIII shows. Since the number of different elements (shape and size) and colors contribute to the perception of a design as diverse (they tried to use as many as different elements and colors when they were concerned with diversity), it seems that 'designers' manifested a limit for the degree of diversity that they could tolerate in their designs.

7.2.10 Design medium

Why did the subjects *fail*?

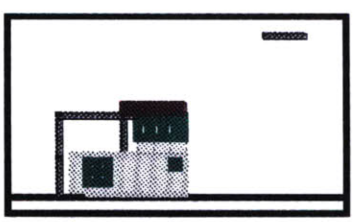
4

Designers manifested a preference for a balance between the occupied and the non-occupied area of the drawing board

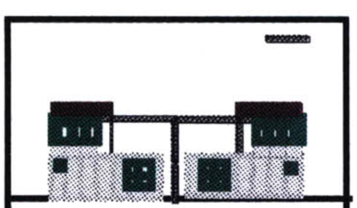
The design medium prevented designers from generating diverse designs

We saw in section 7.2.5 that designers did not use as many elements and colors as those provided by the system. One can certainly argue that the drawing area was too small to allow the use of more than a certain number of diverse elements and color-patterns. Nevertheless, designers did not use more than a certain area of the drawing board, and that area was considerably smaller than what non-designers used.

If we measure the area of the drawing board occupied by the designers' designs we observe (Table B.VIII) that these drawings occupy between 19% to 46% of that area. The lower and upper limits of this range corresponded to Salvatore's design (Fig. 7.46) and to Taylor's design (Fig. 7.47), respectively. Nevertheless, we can correct, the values of their designs, and by doing so, the values for all the designers' designs become remarkably close: 28%-33%.



15 - After correction



16 - After mirror operation (see verbal protocol)

Fig. 7.46
Salvatore's design before and after the mirror operation

As can be seen, Salvatore's design was considerably smaller than all the other designs. However, if we consider his design after the mirror operation that he suggested while he was designing, and that I did under his supervision after he finish the design, it occupies 33% of the drawing area, compared to the initial 19% (Fig. 7.46, table B.VIII).

Taylor was replying to Wade's design, and because the printed image of Wade's design was bigger than the drawing board on the computer screen, Taylor lost the *sense of scale*, and his design exceeded the drawing board (Fig. 7.46. In other words, Taylor manifested a concern with the scale until he built the entire structure of his facade defining its final size, as the following verbal protocol shows. At the beginning he asked if the scale on top part of the computer was working:

> *T: That measurement thing up there doesn't work, does it?*
>
> *J: No, it doesn't work. If you want to know the scale, a person is about that size.*

When I unwittingly told him that the scale was not working, I obliged him to rely exclusively on his perception of Wade's drawing, in which the panels division was not visible. Because the printed image of Wade's drawing was (about 1,5) bigger, he noticed later on:

> *T: How come that building looks so much bigger than mine can possibly be?*

And, he asked again:

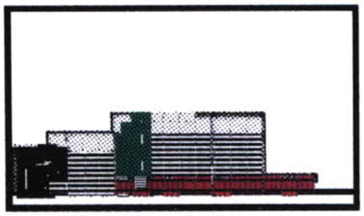
> *T: What did you say the scale of a person is?*
>
> *J: About this size.*

Finally he acknowledged that he could not reply to Wade's design unless he went out of the drawing board.

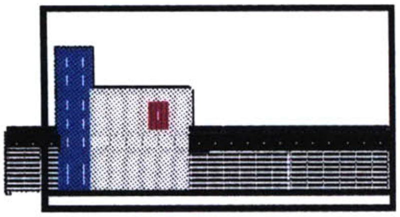
> *T: (...) Then I am trying it to be a kind of cascade. This actually in response to this building, some kind of a reverse of that. A reverse composition. Is it possible for me to go outside this boundary?*
>
> *J: No.*
>
> *T: I'm help by the time be. This comes to help like this, or so, it has just occur to me that I can make this a higher element, which means that somehow I get some section here, where I can imagine some light and visual contact between this way and this way. Yes?*
>
> *J: Yes.*

Although I told him that he could go out of the drawing board he was still puzzled by the difference in scale between the two drawings:

> *T: Did you did this this smaller because this took too long?*
>
> *J: No, it is just the size of the screen.*



1 - Wade's final design



2 - Taylor's final design

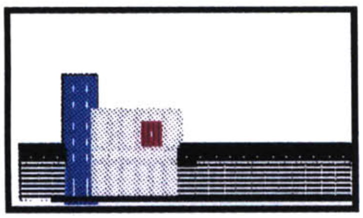


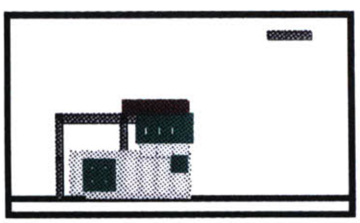
Fig. 7.47
Wade's design and Taylor's reply to his design stepping out the drawing board, and shrunk to fit within it

T: Let's just see how big that was. Yes, this the same size of screen. It was done right here. It just looks for some reason deceiving.

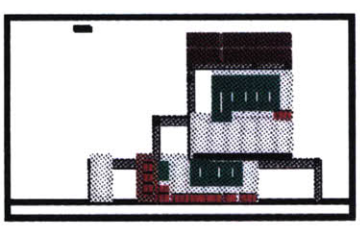
Therefore, Taylor's referential was Wade's drawing, whereas the other designs referentials were their own drawing boards. So, if we want to find the area of the drawing board occupied by Taylor's design in order to compare it with the values of the other designer's designs, we have to decrease his so that if fits within the drawing board. In these circumstances Taylor's drawing fits within the drawing board and occupies 31% of its area.

Like Taylor, Ming was also replying to another designer's design. The analysis of Ming's behavior replying to Salvatore's design does not contradict our analysis of Taylor's behavior but reinforces the argument that designers tended to fill only a certain area of the drawing board. Ming was looking at a copy of Salvatore's design before the mirror operation (fig. 7.48). Ming examined carefully Salvatore's design at the beginning, while Taylor looked constantly at Wade's design until he defined the size of his facade. Moreover, in his analysis of Salvatore's design, Ming counted the exact number of elements that made up its surfaces trying to find relevant proportions.

M: Well, I am trying to figure out if there are any relationship, dimension wise that the roof as... whether the facade is divided into certain proportion. One, two, three, four. So, it seems like the roof is four to one, the roof, if I use the roof as the dimensional, the base, the reference, as a reference dimension, and there is four part to one. And it seems like three wall panels equals three and a half window space. I don't what that means, but... One and a half panels equals one square window. It seems that half of a panel, half of a wall panel in height equals the height of the square window. Can I draw another tracer so I can...



1 - Salvatore's final design



2 - Ming's final design

Fig. 7.48
Salvatore's design, and Ming's reply to his design

Hence, Ming was concerned with the proportions between the different parts of Salvatore's design, whereas Taylor was more concerned with the overall size of Wade's design. However, if we measure the area between Ming's and Salvatore designs, it is exactly the same between Taylor's and Wade's designs, and the same between the printed and the computer images of the drawing board. Therefore, although Ming did not loose the sense of scale, like Taylor did, he changed the size of Salvatore's design in order to make his design fill a certain area of the drawing board that he considered satisfactory.

Consequently, we can state that designers used between 28% and 33% of the drawing area available. Therefore, designers' designs exhibited a preference for a certain balance between the drawing area that they occupied and the total drawing area available. On the other hand, non-designers designs occupied 51% of the drawing area (Table B.VIII). The gap between designers and non-designers suggests that architectural education influenced the behavior of the designers. Non-designers were merely concerned with the representation of their ideas whereas designers were also concerned with the aspect of the design artifact itself. For instance, Ana, a non-designer, did not mind to represent only partially the fifth house of her design, since it did not suit the drawing board. Although she noticed and commented the fact, she did not change her design to suit the drawing board.

If the designers could not tolerate more than a certain amount of different elements and colors within a certain area, by restricting the area of the drawing board, they restricted the number of different elements and colors in their drawing. As a result, they restricted the diversity of their designs. In conclusion, the results of the experiments suggest that due to architectural education, the design medium influences designers in a way that prevents them from generating diverse designs.

7.2.11 The decision-making process: the need to freeze variables, and the need of logic,

Designers (and non-designers) decision-making process, characterized by the need to freeze variables, and the need for logic, prevented designers from generating diverse designs

We saw in Section 7.2.7 how subjects restricted the system's design world, because they disliked some of the shape primitives or attributes, or some of the possible spatial arrangements between them. Although fewer, the remaining number of possible design solutions was still great. How did they move towards their final design solutions? In other words, how did subjects make decisions when 'they were left' only with design solutions they enjoyed?

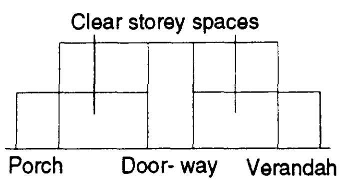


Fig. 7.49
Scheme of Wade's conceptual idea

The results of the experiments showed that besides the restrictions prompted by taste criteria, the subjects also eliminated some design possibilities that remained opened or unconstrained by design requirements. The results suggest that the design process evolves with a constant need to freeze variables. Moreover, the decisions associated with the process of freezing variables are made on a logical basis rather than randomly. Two of the experiments one with Wade and the other with Ana can be used to illustrate the two assumptions mentioned above.

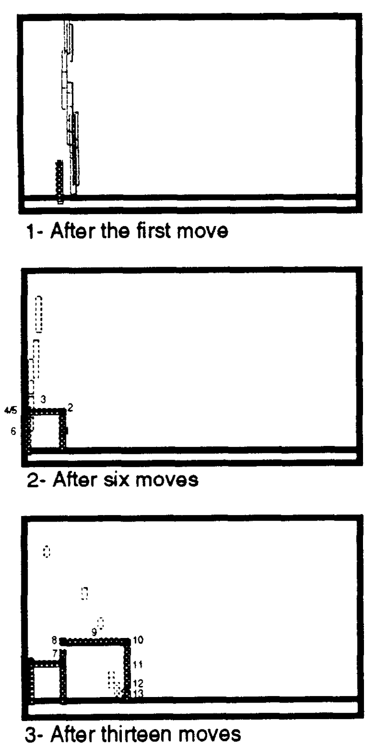


Fig. 7.50
Wade's design process

Wade's design process Graphic Protocol is shown in Fig. B.4, analyzed in detail in Fig.B.10 (Appendix B), and partially summarized in Fig. 7.50. In this figure, the actual states of the design are shown in bold line frames, whereas hypothetical states or analysis diagrams are shown in thin line frames. Wade started his design building a structural frame (Fig. 7.50-1 through 9), following given procedural rules of the system:

> *[...] I am just trying to get the structure for the interior space first, and then I will put the panels and the windows later.*

Wade was concerned with building a structure that allowed him to have some sectional differences in response to the problem of diversity .

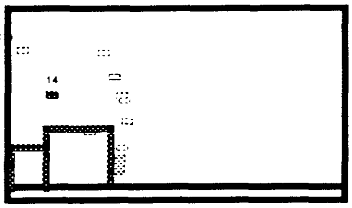
I am trying to get some type of structure that will let me have some sectional differences between the space defined by this tall column and the extra long upper space, a sort of a clear storey space.

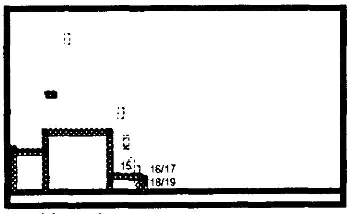
He was also concerned with building a structure that corresponded to his idea for the design, which was:

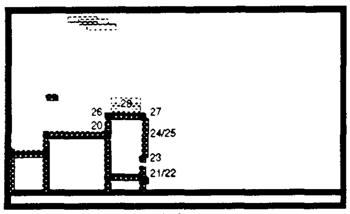
W: This is going to be a central entrance doorway between the two spaces. [...] I guess the program of this thing could be anything but... it looks like... It's probably a house. [...] I had some idea of two spaces with a verandah... a porch, maybe two.

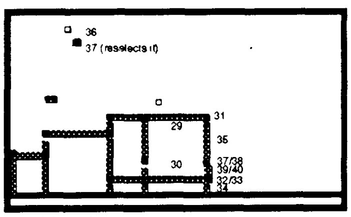
Wade had no particular problem deciding about his structure because the problem was constrained enough to significantly reduce the range of possibilities. For instance, he first designed a small structural bay for his left side porch, then a big one for his left-side 'clear-space' (Fig. 7.50-2 and 3). Then he decided to raise the structure to continue with his idea of getting a sectional difference. In order to achieve a maximal structural variation, he also intended to use a very small beam but he reject it because the resulting bay would be too small for the door-way (Fig. 7.50-4). He used, then, a beam as big as the one he used fot the porch (Fig. 7.50-8). Then he designed a bigger one for the right-side 'clear-space' (Fig. 7.50-7). If he lowered that space he would start getting an obvious symmetry (Fig. 7.50-?), so he decided to maintain it raised. He also decided to make that space bigger to make it even more different, by adding another structural bay, different from any of the existing ones (Fig. 7.50-8). Nevertheless, he saw the new bay as a second space within the first one, which means that although he accepted that the design was not visually symmetrical, it was conceptually symmetrical:

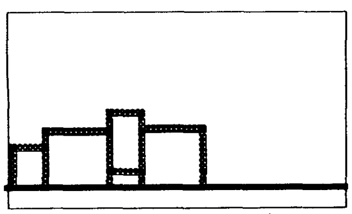
Well, I am trying get another... a second space within the first one and a... I am trying to get a porch in one end with a roof in extension covering it.


4- After fourteen moves


5- After nineteen moves


6- After twenty eight moves


7- After forty moves


7a - Possibility not selected

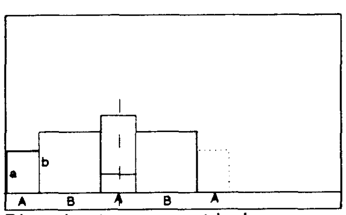
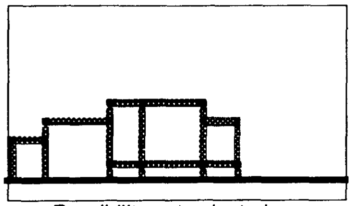
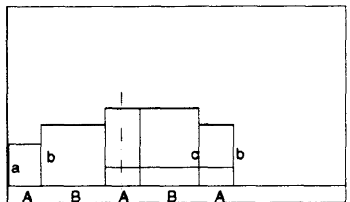

Diversity: too symmetrical.

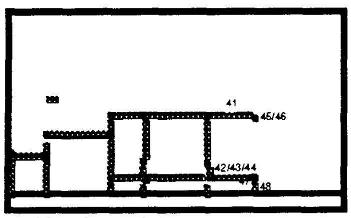
Fig. 7.50
Wade's design process (continued)



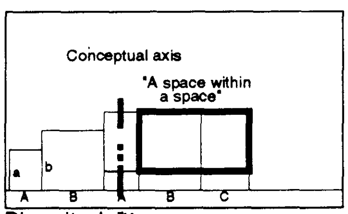
8a - Possibility not selected



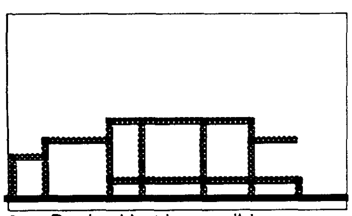
Diversity: Too symmetrical.



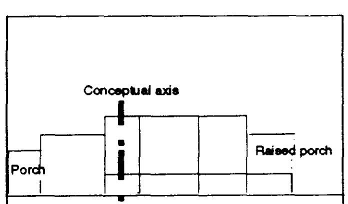
8- After forty eight moves



Diversity: better.



9a - Desired but impossible: cantilivers not allowed



Diversity: good. Right porch different from left porch.

Fig. 7.50
Wade's design process (continued)

He wondered whether he should or should not design a second open porch on the right hand side. He could not make a decision because none of the design possibilities were feasible or satisfactory. On one hand, he wanted a cantilever but that was not possible in the system (Fig. 7.50-9a). On the other hand, if he built another structural bay, the design would become symmetrical, and thus less diverse (Fig. 7.50-9b). So he did not build anything (Fig. 7.50-9).

Once Wade finished the structure of his facade, he faced the problem of how to clad it with the wall panels. But then, he faced a new difficulty. Unlike for the structure, there were no constraints to help him to make a decision. He stopped for a while, and finally he said:

> *Now let's start putting some panels there. The volume up there is... There is nothing there, so let's put* ***something that looks substantial.***

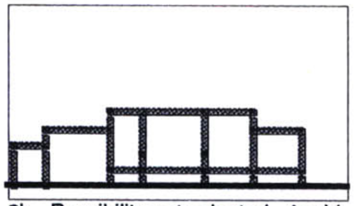
So he used the red brick for the 'grounding' underneath the raised structural bays, and stated afterwards:

> *So, choose the white brick for the main level, and the whitewash for the clear-story levels.*

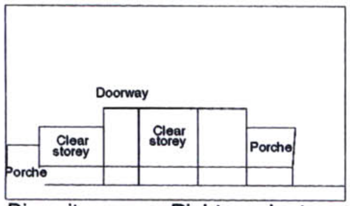
Wade was aware that the placement of the panels implied another level of difficulty. Additionally, he needed to formulate his decisions about the cladding into a coherent rule. Later he said:

> *The commonalties are not in the structure but in the panels. There is three different , sort of conditions of the materials in terms of just massiveness, and white is probably one of the real common... The plain white panels could be made of stucco, and the white brick is masonry, so it has some tectonic reading, but it has this white color. Then you get to the red brick which is larger in the size of the unit, and because of the color, which is a darker color, it is an earth tone, so it reads as... something to be read as a grounding. Whereas the red, the blue, the green, the black windows are basically... unless somebody has some type of methodological approach to color...*
>
> *So... let's put the rest of the white panels. So as I was saying... how people choose the design elements they are given to choose from. Basically, structural elements are*

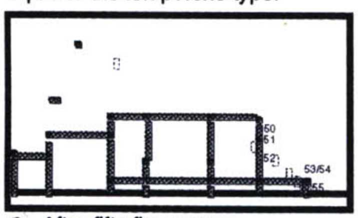
structural elements. It's just a matter of arranging. I am trying to think about that idea of... of how people relate to the several elements, and (I am) trying to design at the same time.



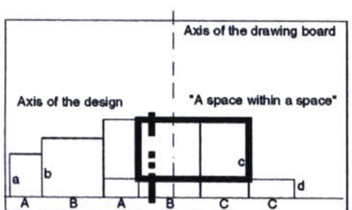
9b - Possibility not selected. Avoid obvious symmetry.



Diversity: worse. Right porche type equal to the left porche type.



9 - After fifty five moves



Diversity: better.

Fig. 7.50
Wade's design process (continued)

Wade's dialogue with himself suggests that he was trying to find a rule (or a theory) that supported his decision-making process about the placement of panels. Interestingly enough, he used a metaphor to develop his rule, according to which shapes were assigned a certain visual weight depending on their color, and the materials they represented. Wade's panel placing rule supports the idea that people use metaphors in designing and the theory we proposed in Section 7.1.9 for how people perceive color in terms of weight—darker colors look heavier, and lighter colors lighter. The development of Wade's rule had three different aspects. First, Wade assigned a visual weight to the different panel colors available and ordered them accordingly—red brick (heavier), white brick, whitewash, and glazed panels. Second, he decided that heavier colors should be on the bottom, and lighter colors on the top. Finally, he assigned a specific function to each type of panels—red brick panels for the grounding, white brick panels for the clear-story spaces, whitewash panels for the upper spaces, and glazed panels for the circulation areas. A hypothetical construction of Wade's design according to his rule is shown in Fig. 7.51. In reality, he was prevented from following his rule exactly. Right before he synthesize the thoughts above he said:

W: [...] stacking the windows on the top of the panels below, is more keeping the way that modular systems work. But, I think it would... I don't know... If it...If it is a rule you have or not... I think it would be good to be able to stack the windows as you do with a panel, and also to cut a hole into a panel and put the windows.. So hat the windows can work as this large modular panel. So that you have two different window conditions: you can cut into a panel, and also you can use the window as a panel. So, that the windows start to work into two different ways. That would give you another level of variety... and also of difficulty.

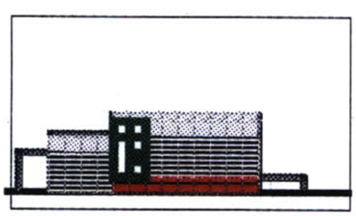


Fig. 7.51
Hypothetical construction of Wade's design according to his cladding rule

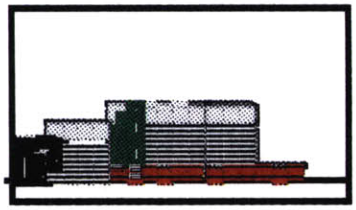


Fig. 7.52
Although Wade's design process did not entirely follow his cladding rule, the final design was still a result of his rule

Beyond the criticism implicit in Wade's comments[2], it is also possible to infer other information. Because Wade did not have glazed panels he had to place opaque panels before he placed the windows. However, by doing that he broke his panel-placing rule, according to which each type of panel was assigned to a specific function; there was no clear mapping between a color/panel and a functional space. Nevertheless, Wade would place the panels and windows in such a way as to maintain his rule as much as possible (Fig. 7.52). Wade's behavior reveals three important points. First, Wade needed to 'freeze variables' to proceed in his design process; second, he did so by creating a logic (a rule) that assisted him in his decision-making process —the variables position and color of a panel could only take values that respected his rule whereas the variable size was constrained by the size of the area to clad; the search space was restricted and decisions easier to make. Finally, logic became an important design constraint itself.

Ana's design also supports the idea that a need for logic rests behind the decision-making process. In effect, to a certain extent, the process is even clearer in her case. Not only did Ana start her design process by defining the rules that she was going to use in her design process, but she also was considerably more aware of those rules. At the beginning of her design session, she defined her first rules:

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[2] Obviously, Wade was correct in his criticism. When I had to choose which elements to use in the drawing board I used less elements than those provided by the system I developed because the drawing board was not big enough to display all of them. Nevertheless, I considered appropriate to use fewer elements because my argument was that designers restricted the possibilities of a given system and not that a given system was able to provide all the design solutions (the universality problem discussed in Section 3). Moreover, if I could demonstrate (as it happened) that a small number was able to generate diverse designs, I would reinforce the argument that a building system can be used to create diverse designs. I also thought that it was better to provide enough elements of a certain design world in order to give designers a significant range of design possibilities in that design world, than to provide fewer elements of two clearly distinct design worlds, which would restrict the design possibilities down to a small number if designers clearly chose to operate in only one of those worlds. Of course I chose the one that corresponded to the most common situation in modular systems as Wade pointed out.

I am going to try to draw facades, attached, not very tall, to be faster, and attached because as there are no trees it would look a little bit desolate, if I left empty spaces.

Then she proceeded to define her other rules:

I didn't want the doors at the ground level, and as I thought that we could distinguished the big modules from the small modules, I decided to put the bigger on at the same level of the door. Do I have to put the doors after the panels? I am going to put the windows after the doors because I don't know how... It is boring to build the walls. We should be able to put only the windows, because the windows point out the painted area. One more... because the window cannot be attached to the door. There should be bigger walls... There should be higher walls...

All of Ana's rules developed during her design process are shown in Appendix B.6. How can we interpret Ana's need for such rules? As we saw in Wade's case, in order to develop a design out of the set of given elements, a designer in the circumstances of our subjects has to make two different kinds of decisions at each move, not necessarily in the following order. First, he has to decide which element he should pick up. Such a decision implies instantiating the variables size and color-pattern into any of its possible values (Table B.III), freezing all the other possibilities. Second, he has to decide where to place the selected elements, which means to instantiate the variable position into any of its multiple values. The rules that Ana created Ana's rules helped her to restrict the range of possible values for the design variables, and thus, those rules helped her to make such decisions. Therefore, she developed her rules due to a need to freeze variables in order to make decisions.

Ana did not only use rules to restrict the range of design possibilities. Besides using her rules, she also used a paradigm to inform her design process:

The brown should be closer to red, because this way it looks like wood. Can I ask you something? Should I put a

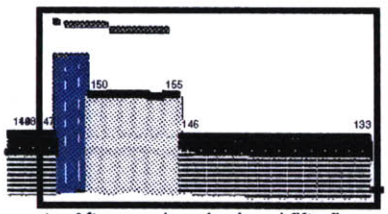
Fig. 7.53
Ana's paradigms: The Back Bay, in Boston (USA) and a fisherman's village in Portugal

panel behind the door? The door is smaller... ***I am influenced by the building*** *where I live. A door and a window.*

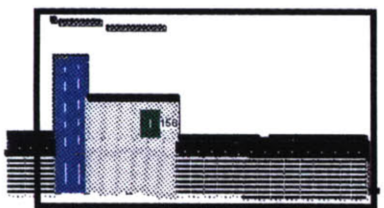
Later on, when she realized that she could not achieve the same degree of decoration of her initial paradigm she shifted her paradigm:

> *And now a window. I am going to make it fancier. No...In this I am going to put some decoration, but later... I think that my Beacon St. is going to change to a fishermen's neighborhood.*

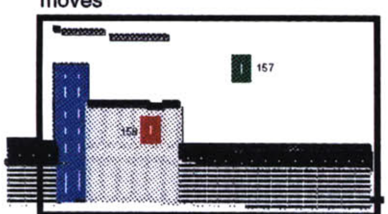
Nevertheless, she did not significantly shift her rules, but rather developed and completed them. Like her rules, Ana's paradigm helped her to make decisions. By choosing a paradigm she reduced the range of possible design configurations down to a set of possibilities that resembled her paradigm.



1 - After one hundred and fifty five moves



2 - After one hundred and fifty six moves



3 - After one hundred and fifty eight moves

Fig. 7.54
Taylor could not consciously justify the placement of a window at the end of his design process

The analyses of the Graphic and the Verbal Protocols of the other subjects' designs confirm the use of rules and or paradigms by designers during their design processes. Both the uses of rules and paradigms demonstrate that designers need to freeze variables in order to make decisions. Furthermore, they also show that designers need to support their decisions with logical reasoning; it is hard for them to make decisions randomly. A caricature of this is given by Taylor, one of the designers. At the end of his design, Taylor felt that he should place a window at the center of his design (Fig. 7.54). Apparently, he did not find a reason to place that window, so he explained its placement, by saying:

> *You always need something exciting (isolated window). I can pick any one I want. Oh, no red is too... Maybe green, maybe green will look better. Green is closer. My grandfather's favorite color was green.*

Note that Taylor even needed to find a reason to pick up a certain color. Because his grandfather's favourite color was green he placed a green window. He would, nevertheless, substitute the green by a red one for other reasons, as we shall see in a later section.

It is not hard to find this design logic among the works of well-known architects. Even explicitly. Peter Eisenman is a good example (Fig. 7.55). It is, however, important to note that these logic rules are defined as the design evolves, rather than constituting an a priori construct. Wade's and Ana's design processes, discussed above, seem to confirm this process. These logic rules are, thus, a puzzle that is completed at the end of the design process. This viewpoint confirms the idea that the

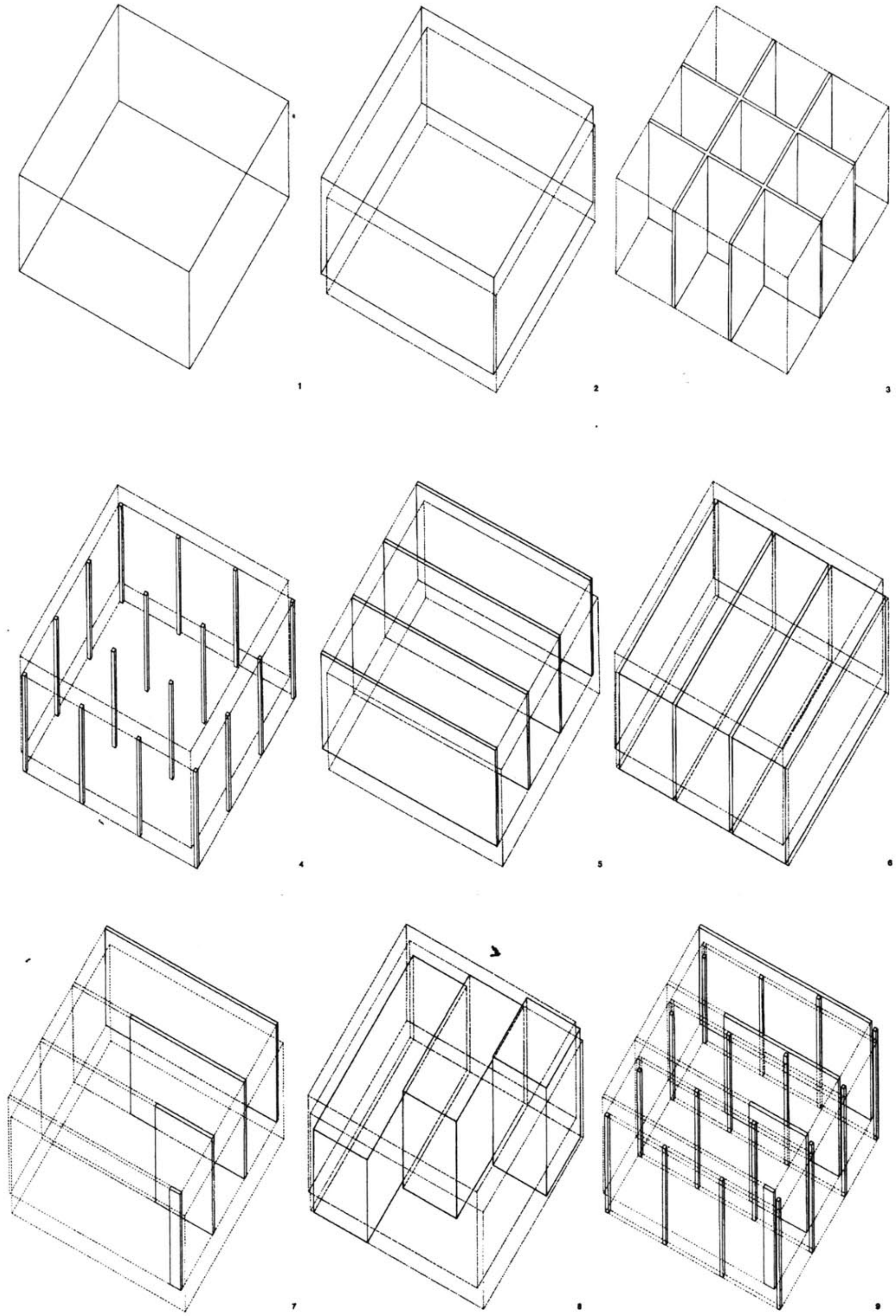


Fig. 7.55
Peter Eisenman, Casa II 1969
Eisenman used a geometrical logic to explain the generation of his design

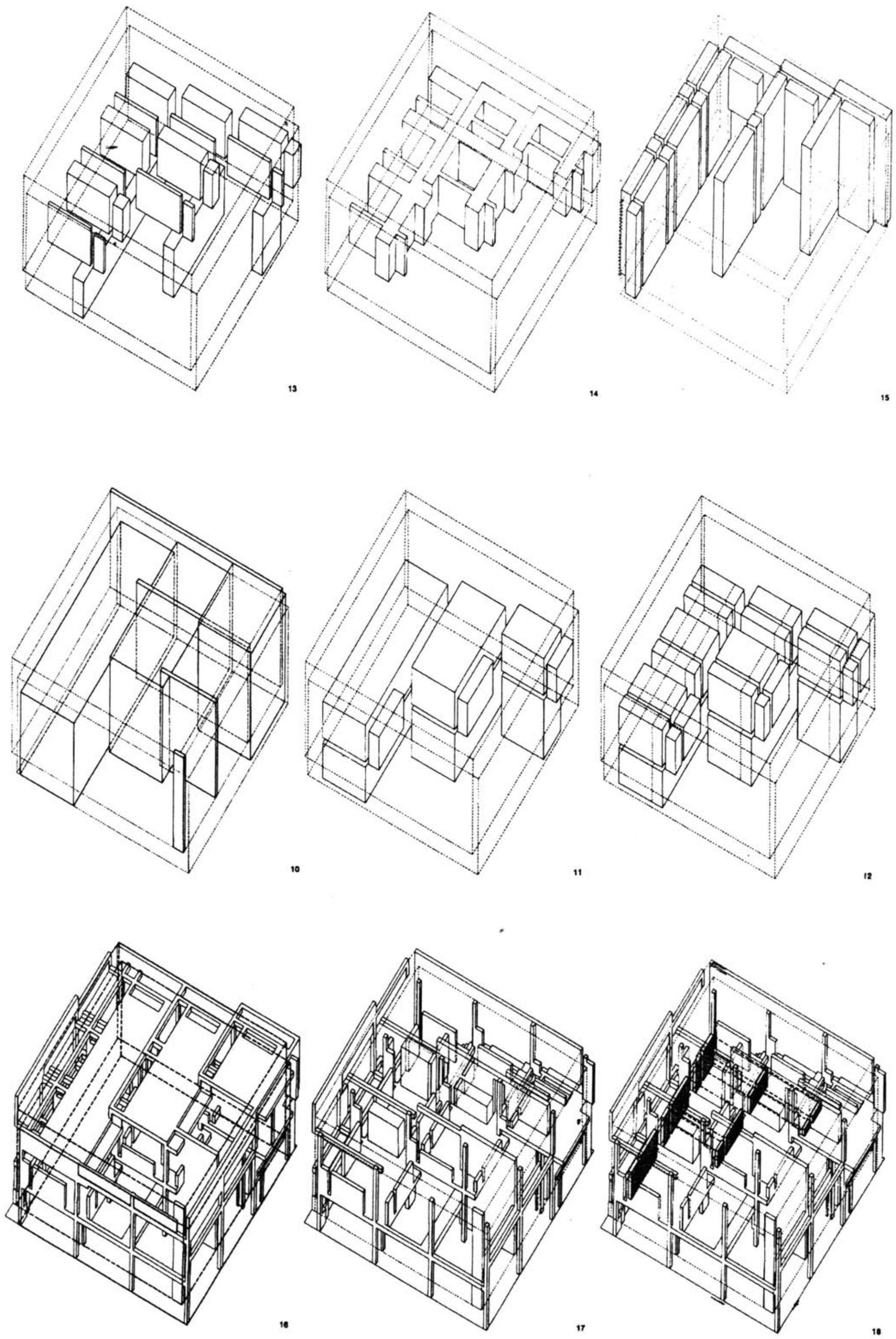


Fig. 7.55
Peter Eisenman, Casa II 1969

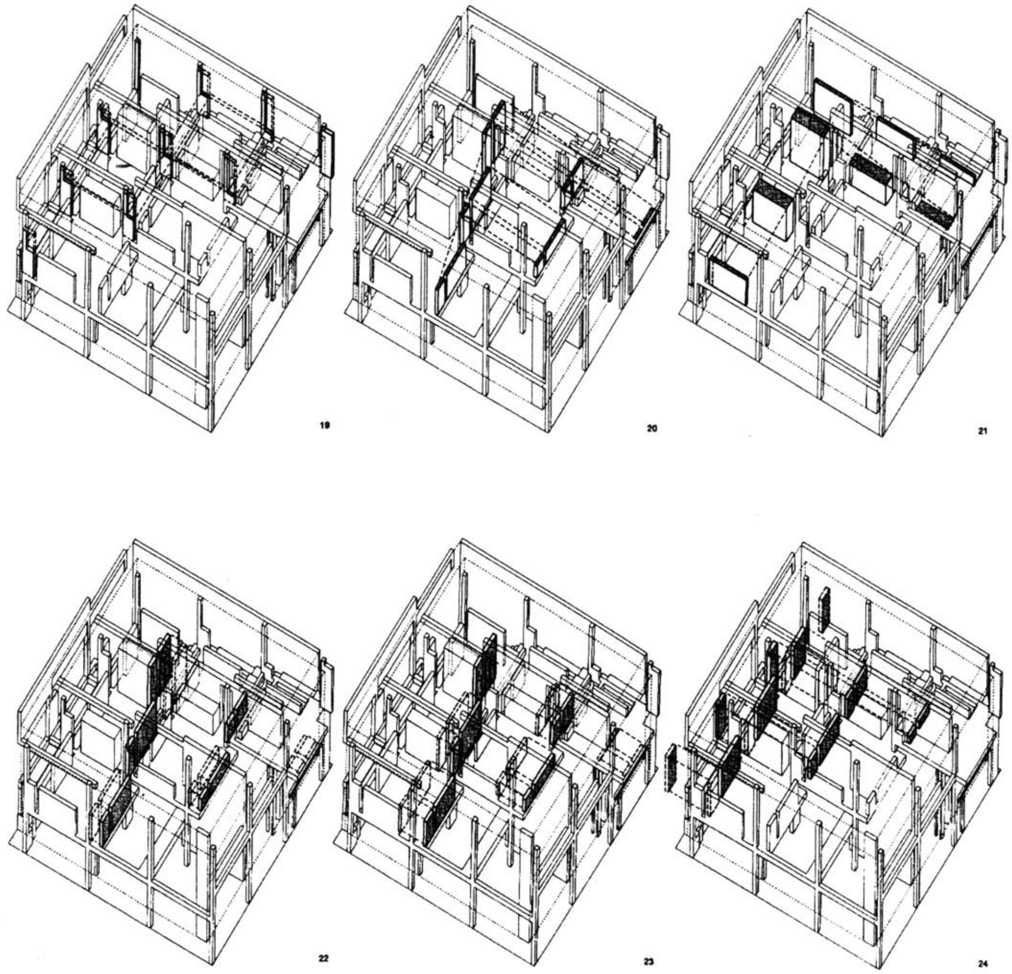


Fig. 7.55
Peter Eisenman, Casa II 1969

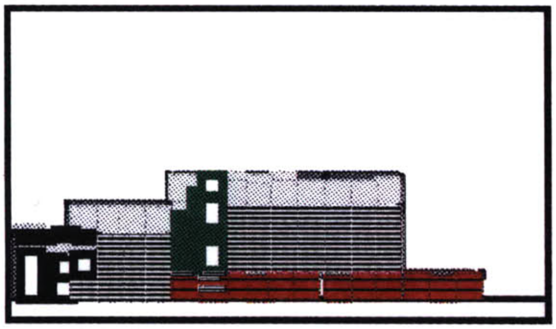
architectural design process is puzzle-making (John Archea, quoted in Papazian 1991). However, these logic rules are not the design process itself, even if architects like to make us believe so. They only describe the design process without the cross-cuts and the dead-ends that architects run through during their search.

These logical rules are like two-sided coins. On one hand they help a designer to make decisions, reducing the search space. On the other, they also prevent diversity, since the entire design will obey the logic it creates. If the design is a large scale development, no matter its scale, it will obey to the same logic. It constitutes the element that helps to define and identify the language of a designer that he transports from project to project. Interestingly enough, the creation of an architect's language is, thus, constructed on the basis of a repetition. This repetition might constitute an unifying element, but it is also a factor of non-diversity, depending on how restrictive the rules are.

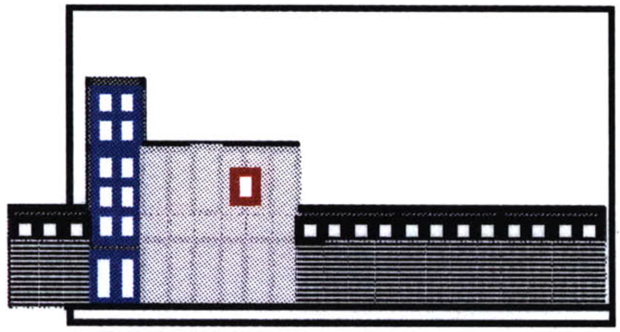
The designer's need for logic helps us to understand why designers have trouble generating diversity. When I asked Taylor, who was replying to Wade's design, whether he considered his design diverse, he defended himself saying:

> *This is as diverse as that. This guy used some chaotic window type to try to create diversity. I think it is a poor excuse for diversity.*

In other words, Taylor suggests that in order for something to be chaotic, there has to be a reason behind it. The analysis of Taylor's design shows the implications of such an idea. Because he saw no reason to design a random cluster of windows, he transformed Wade's random cluster into a simple and ordered one, in which diversity is considerably less apparent (Fig. 7.56). Stating this principle more clearly, I would say that it



1 - Wade's design



2 - Taylor's design

Fig. 7.56
Because Taylor saw no reason for the existence of a random cluster of windows in Wade's design, he transformed it into an orderly one in his own design

seems that designers need an excuse to generate diversity, because if there is none, they generate repetition. This principle reminds me of two laws: one from Physics, and the other from human behavior studies. The first is the law of inertia, which states that a body will remain stopped or moving at constant speed (if it was already moving), unless a force is applied to it. The second, is the principle enunciated by Freud, and commonly known as the law of the least effort, that states that people tend to spend as less effort as possible in their attempts to accomplish something. According to this law a person walking from one point to another, for instance, tends to walk straight, unless he is preventing from doing so by any existing hurdle. The existence of these two laws to explain such different behaviors suggests that the universe is ruled by the principle of inertia. Accepting this, helps us to understand why designers do not generate diversity. First, generating diversity requires a bigger effort and is more time-consuming that not generating diversity. Second, since designers have a limited memory capacity (as we stressed in previous sections), they are not able to take into account minor design requirements. Because they do not remember minor design requirements, but they need a reason to change parts of the design that should be otherwise equal, they find no reason to make those changes, and as a result the design is less diverse. For instance, consider the case of a designer who has to design several row-houses for different families. A certain family prefers green windows, whereas another family prefers red windows, another one blue ones, and so on. It is hard for the designer to remember those different requirements, especially if variety is also to be extended to other design elements. So, in order to cope with the complexity of the requirements, and because of his limited memory, the designer abstracts and reduces the variety of the requirements. In this way, because the designer needs to explain what he is doing, but he cannot remember, or does not know, all the details about the design requirements, he cannot explain different design outputs for the (apparently) same design problem. So, most likely, he designs equal windows for the different families' houses. Therefore, he is prevented from generating diverse designs.

Ana's design process is a paradigm of the logic that designers construct during their design processes prevents them from generating diversity. Ana's logical reasoning is diagrammed in Fig 7.57.

Through logical reasoning, Ana arrived at a prototypical solution; a solution that exactly fit the design requirements and the constraints that she defined for herself. However, her solution became so important, that three out of the four complete houses that she designed corresponded exactly to the prototype. Only when the lack of diversity became too apparent did she design a variation of her prototype—a house with two windows that could, nevertheless, be read as a single window. Therefore, her logical reasoning prevented her from generating a more diverse design.

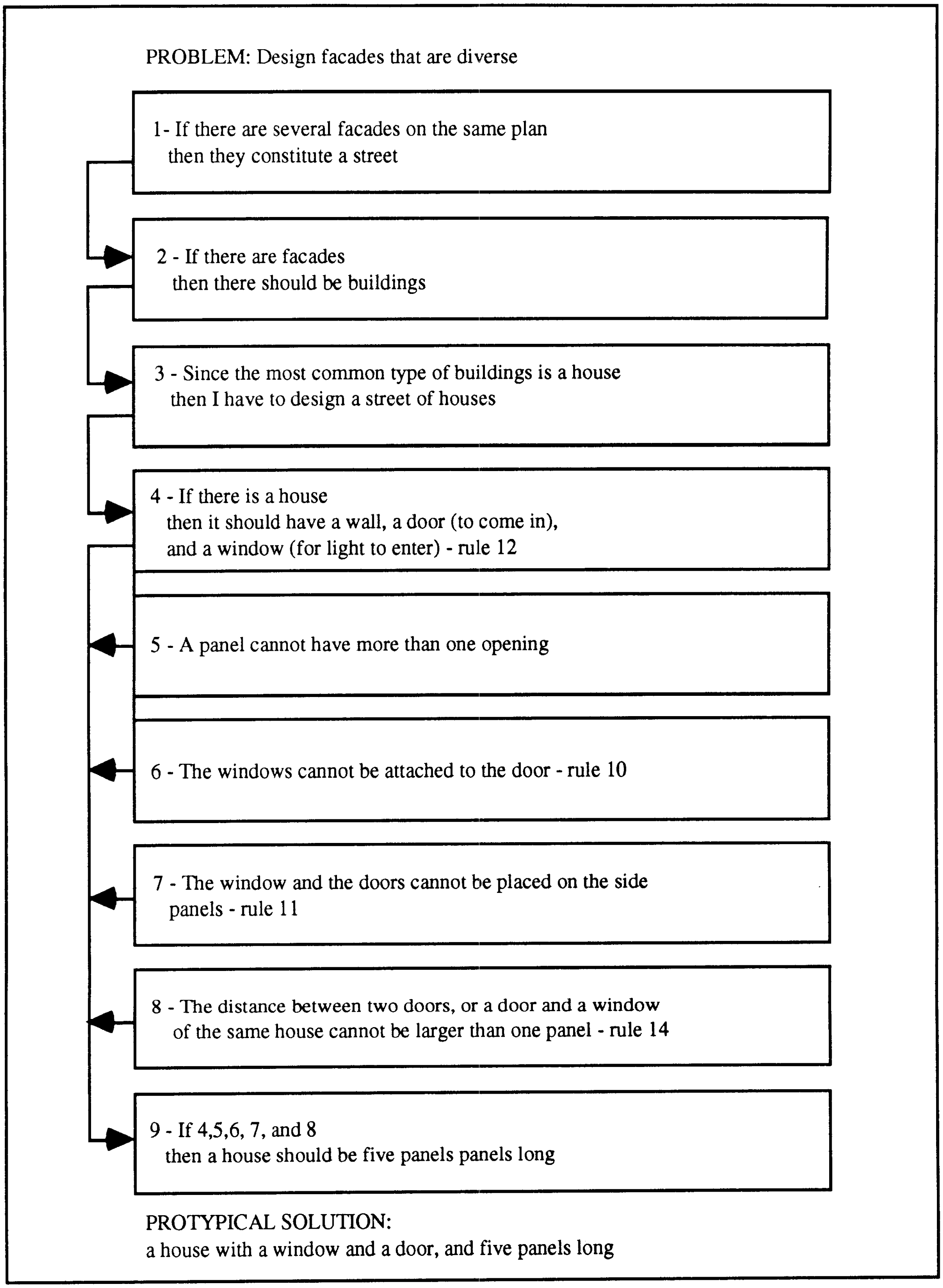


Figure 7.57
Diagram of Ana's logical reasoning after her Graphic and Verbal protocols: from problem to prototypical solution

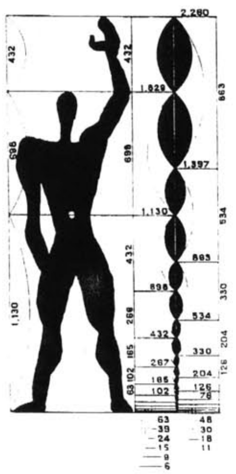
In conclusion, due to limited immediate memory capacity, the decision-making process that occurs during the design process involves a constant freezing of variables, and is informed by a principle of logic according to which decisions ca not be made randomly. Logic and freezing of variables help designers to cope with the complexity of reality, and move through the high number of design possibilities offered to them at the beginning of a design process. However, since designers are not able to remember small design requirements but do not make decisions randomly, they are prevented from generating diversity.

7.1.12 Prescriptive versus proscriptive rules

Prescriptive rules are more flexible than proscriptive rules and therefore can be used to generate diverse designs

In the previous section we saw how designers created rules to help them to make decisions. I speculate that the idea that designers need to freeze variables and to explain design decisions also help us to understand the development of design rules in architectural theory such as proportioning systems. These rules can be proscriptive or prescriptive. Proscriptive rules are closed rules and so their use restricts diversity, whereas prescriptive rules allow variation. These differences should be taken into account in the development of design rules for facades.

Proportioning system are aimed at combining dimensions in such a way that the most beautiful proportion results, and so are often used to regulate facades. I argue that proportioning systems also help designers to make decisions. Without a proportioning system designers have a large range of design possibilities. With a proportioning system, not only are designers able to restrict the range of design possibilities, but they are also able to justify why a certain building or a facade as a certain proportion and not another. Therefore, it is easier for them to make a decision.



However, proportioning systems do constitute a constraint in the generation of diversity when they prevent designers from varying similar parts of the design. For instance, if a designer finds what he thinks it is the right proportion for a house in a row of houses, according to the mechanisms previously described, he has some reluctance in accepting a variation of those proportions in the neighboring houses.

On the other hand, proportioning systems could be used to generate ordered and diverse designs, since they can be used to generate a set of shapes that have the same proportion but vary in size (Fig. 7.58). However, this is only valid if there are no constraints that prevent slight variations in size, such as structural bays. Otherwise, it only works for objects that belong to different scales (Fig 7.58-a).

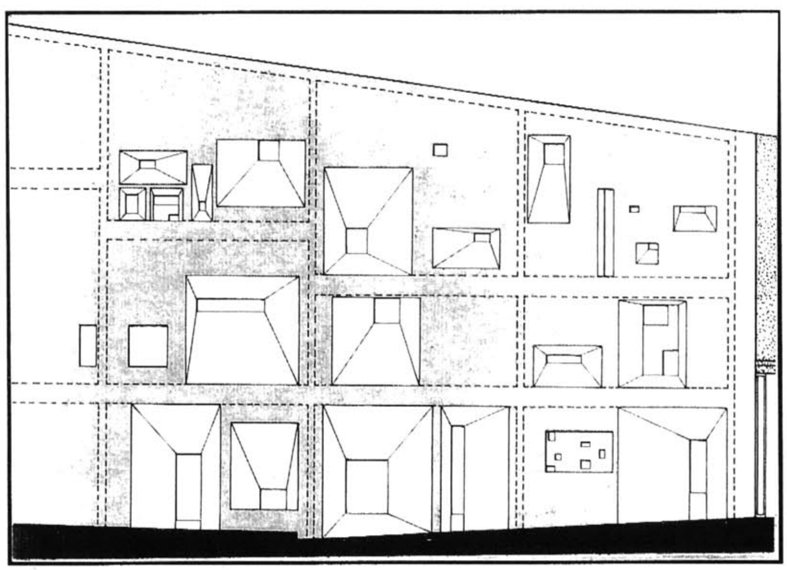


Fig. 7.58
Le Corbusier, 1951, Ronchamp
Use of a proportioning system to generate diverse windows, whose are dimensions dictated by the modulor (top)

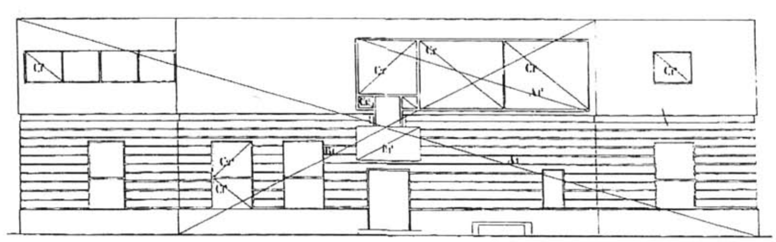


Fig. 7.58 - a
Le Cobusier, 1927, Church Pavillion
Use of a proportioning system to regulsate elements of different scales

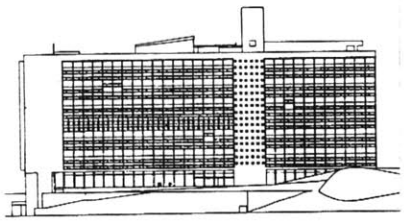


Fig. 7.59
Le Corbusier's, 1945-52, Unité d'habitation à Marseille
Rigid use of a proportioning system. The rigid layout of the structural frame did not allow much variation

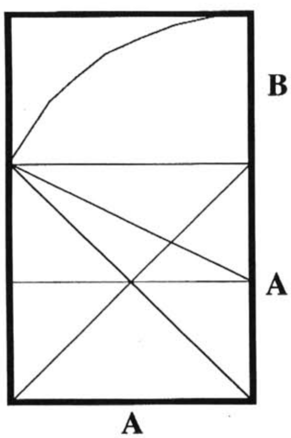


Fig. 7.61
The Golden Section is an example of a proscriptive proportioning rule

Another important issue is the degree of accuracy demanded by the proportioning system. If the proportioning system is proscriptive it leads the designer to generate architectural elements with the same exact proportion. An example of a proscriptive rule is the Golden Section (Fig. 7.60). However, if the proportioning system is prescriptive, it admits some variation, and the degree of diversity is considerably greater. An example of a prescriptive rule would be: a rectangle should have a proportion comprehended between 1:1.5 and 1:2, (Fig. 7.61). Therefore, prescriptive proportioning rules are more flexible than proscriptive rules, and could be used in the generation of diverse designs. In general, prescriptive rules are more flexible than proscriptive rules, and should replace proscriptive rules if diversity is a concern. We will reffer to this issue again in the discussion of the street facade generator.

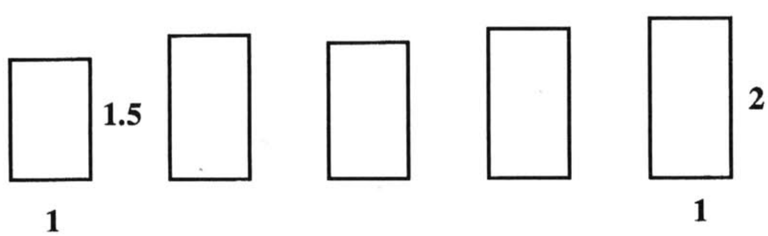


Fig. 7.60
Example of a prescriptive proportioning rule

7.2.13 A decision-making rule

Among several design moves, a designer chooses one that satisfies the most design conditions

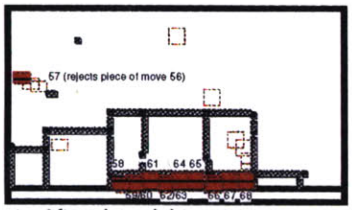
In Section 7.2.11 we saw that the results of the experiment suggest that due to short term memory limitations designers need to freeze variables in order to make decisions, and that they need to do so in some logical way. Additionally, the results suggest that there is a strong need to justify moves in the decision-making process in some logical way is so that a designer makes the one that satisfies the most design conditions. Furthermore, some moves are made only when a designer finds more than one reason to justify them. This rule can be used in decision mechanisms for automated design, like the one proposed at the end of this thesis.

In order to illustrate the rule, I will use some moves from Wade's and Ana's design processes. For more examples consult the Verbal and Graphic Protocol presented in Appendix B. For instance, Wade could not decide whether he should use red brick for the grounding on the right side of his house (according to his panel-placement rule), despite he had already used red brick for the adjacent grounding, until he moved the stairs to the right (Fig. 7.62-9, 10).

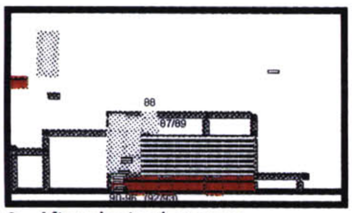
> *I don't know whether the foundation of the porch should be the same or not. So, I am leaving that to later.*

Later his decisions about how to frame the door, led finally to his decision about the porch's grounding:

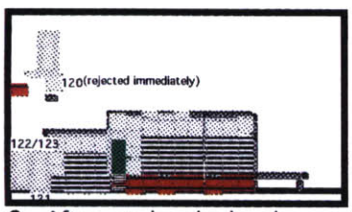
> *Perhaps I should put a door in their while... I'll take the filled door, since there are two different ones. Probably I'll end up putting glass around it.*
>
> *Perhaps the step should be underneath... that the step should go up to the window, and that you turn to the doorway, so that the steps don't go directly up to the door, but go up to the side of the door so you went up to a landing, then you move horizontally. Oh, we can always come back later and move the steps over.*
>
> *Oh, let's go back and move the stairs to where they belong. I want to put the stairs on the right side of the door. Going back to that idea. I don't know whether I will follow the*



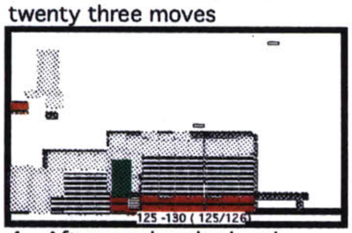
1 - After sixty eight moves



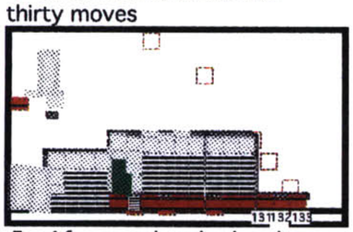
2 - After ninety six moves



3 - After one hundred and twenty three moves



4 - After one hundred and thirty moves


5 - After one hundred and thirty three moves

Fig, 7.62
Wade's design process (partial)

> *rules in trying to define this, because it is a change in plan. This is the first time that the plan has really stepped out of a plane because until now it seem this entire facade is a sort of a single panel. And by moving this steps over and having to have a landing is also the only place where the facade steps out.*

His reading of the stairs as a block stepping out of the plan of the facade, led him to see his house as displaced blocks. The grounding became a unique block displaced by the stairs' block and included the porch's grounding. Interestingly enough, Wade needed two reasons to justify that move. This need, suggests that among different solutions for the same problem, a designer will most likely pick the one that satisfies more rules or the different viewpoints from which the design is evaluated.

A close analysis of Ana's design process reinforces the process seen in Wade's example above. Recall Ana's design process in terms of a search tree (Fig. B.12, Appendix B). At each stage of her design process she had available a variety of possible design moves to transform the current design state to the next one. Note, however, that the move she decided to make was the one that best satisfied most of her rules. The analysis of the other subjects' designs also confirm these assumptions.

In conclusion, between several possible design moves, a designer makes the one that satisfies more design conditions, be they actual constraints, or subjective viewpoints. This decision rule can be used in decision mechanisms for automated design, and will be in fact used in the development of the computer program to design facades proposed at the end of this study.

7.2.14 Conflict, Ambiguity and Opportunity

Why did designers fail?

6

Designers tendency to simplify reality, eliminating conflict and ambiguity, prevented them from generating diverse designs

What factors affect the perception of diversity?

1

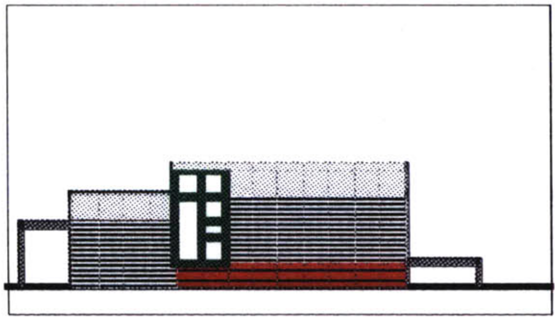
Conflict, ambiguity, and opportunity in design seem to enhance the perception of diversity

In Section 7.2.11 we introduced the idea that designers try to be logical when making decisions during the design process. We observed that their rationalism prevents designers from generating more diverse designs. We also observed that their reasoning does not encode all information to permit the reconstruction of the entire history of the design process, although designers believe they are explaining their decisions. In other words that logic describes their design process eliminating all the conflict that had occurred. The idea that design is conflict is not new and it was best described by Papazian in his master's thesis. According to Papazian:

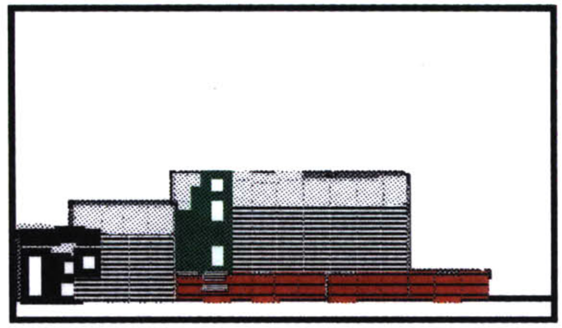
> *Designing is based on a substratum of opportunistic activity. At any given time, the designer focuses on a limited number of components and evaluative criteria. When an opportunity is seen which can be exploited in terms of one of a large number of implicit and explicit values, the designer is distracted by it, and a shift of focus takes place. Focus can be a function of the history of a given design session, the bias of the designer, high-level processes such as planning and inference and, of course, external factors. (Papazian, 1991)*

After these ideas, Papazian developed a model for the design process in which conflicting viewpoint/rules shape the design process. Papazian's model is a suitable model. In effect, without the idea that conflict is inherent to any design process we could not explain some design outcomes. The reason why we happen to be interested in this point of view is that conflict enhances complexity in design, and this seems to be linked to the perception of diversity as can be seen in the work of Wade, Taylor and Ana.

Take for instance Wade's design process. As we saw, Wade developed a panel-placement rule to help him choose panels. Additionally, that rule led him to describe his design in terms of bands. As seen in Section 7.2.11, he basically had four types of bands. Each band corresponded a different function: the lower one—the grounding (red brick), the middle one—the

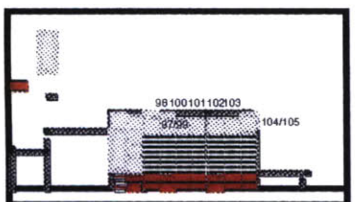


1 - Hypothetical construction of Wade's design according to his cladding (panel-placement) rule

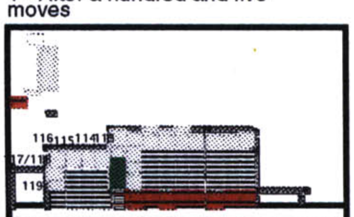


2 - Wade's design

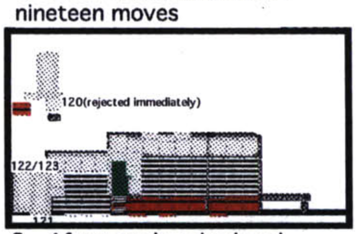
Fig 7.63
Wade's final design is more ambiguous than his rule suggested



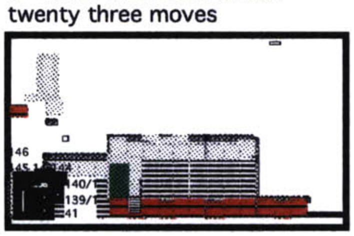
1 - After a hundred and five moves



2 - After one hundred and nineteen moves



3 - After one hundred and twenty three moves



4 - After one hundred and forty six moves

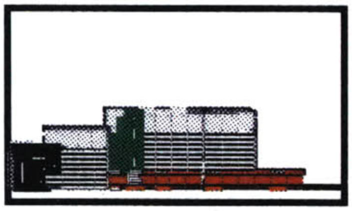
Fig. 7.64
Wade's design process (partial)

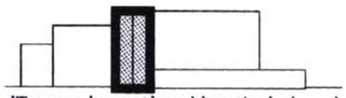
clear story area (white brick), the upper one—the tall area (whitewash), and the vertical ones that corresponded to the circulation areas (glass). There was also an intended progression in terms of massiveness from the more massive bands (below), to the lighter ones (above). However this clarity is not apparent in Wade's final design. On the contrary, his design is more ambiguous than his rule can explain (Fig. 7.63). We suggest an explanation based on the idea that design besides being rational (logic) is also opportunistic in nature.

When Wade decided to clad the glazed central area he realized that he had to place panels before the windows (Fig. 7.64). When he did so, his perception of the design changed and with it his idea for the design changed too. He first placed the white panels below the windows, and then he continued to use the white panels to fill the upper band. Then he was taken by the 'L' rhythm acquired by his design in those circumstances (Fig. 7.64-1) . He shifted his viewpoint, and that shift was purely opportunistic. Moreover, the design medium had an important role in this shift, and he was motivated by compositional aspects.

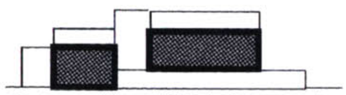
Because of his new perception he tried to replicate the 'L' shape form on the second volume, where there was no apparent reason for it (Fig. 7.64-2), disregarding his panel placement rule. However, he did not replicate the same shape on the left side porch since it seemed to be compositionally awkward (3). Nevertheless, his new compositional viewpoint led him to turn the porch into a glazed space, changing his initial intent (4). Therefore, he had a glazed area on the left side of a white brick area to match the right side of his composition. By doing so, he was creating a new rule—a new logic. However, by he shifting his compositional rules, the new rules contradicted his initial idea and the design became more ambiguous.

Interestingly enough, this ambiguity was the result of conflicting rules. I would argue that ambiguity is an important factor that affects the perception of diversity. An ambiguous design allows multiple readings, and thus, it is perceived as more diverse than one that is less ambiguous. For instance, when Taylor was asked to reply to Wade's design, his first step was to observe Wade's design and extract what he considered the essential features of that design. In other words, he abstracted from Wade's design what he subjectively considered meaningful. However, he did so in such a way as to eliminate conflict (Fig. 7.65). Note how Taylor's design is clearly less ambiguous than Wade's. Because it is less ambiguous it allows less descriptions. It also has fewer visible elements and colors (Table B.VIII). It is thus less diverse.

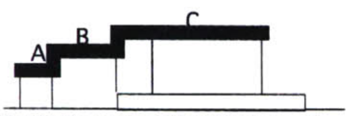




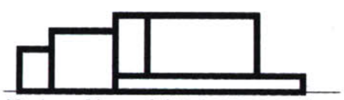
'Tower element' and 'vertical glazed elements' (Verbal Protocol).



'Horizontal 'band' (Verbal Protocol)

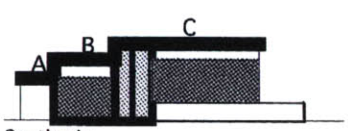


'Kind of cascade' (Verbal Protocol)

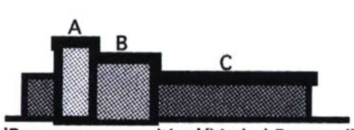


'Series of boxes' (Verbal Protocol)

'Fields of material' (Verbal Protocol)



Synthesis



'Reverse composition'(Verbal Protocol)

'I thought it was compositionally awkward, and now there is some sort of continuation through the building' (Verbal Protocol).

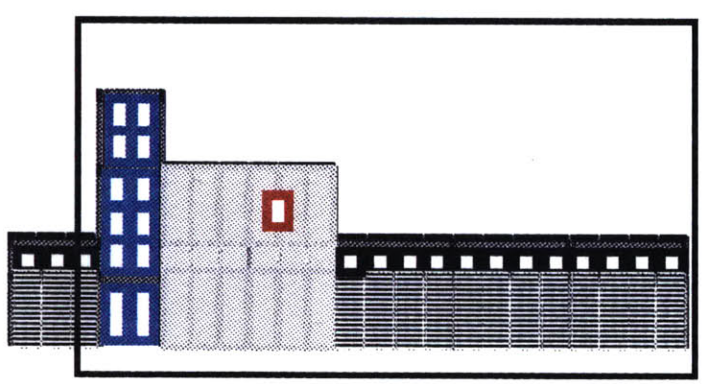


Fig.7.65
Taylor's abstraction of Wade's design, led him to generate a less ambiguous and diverse design

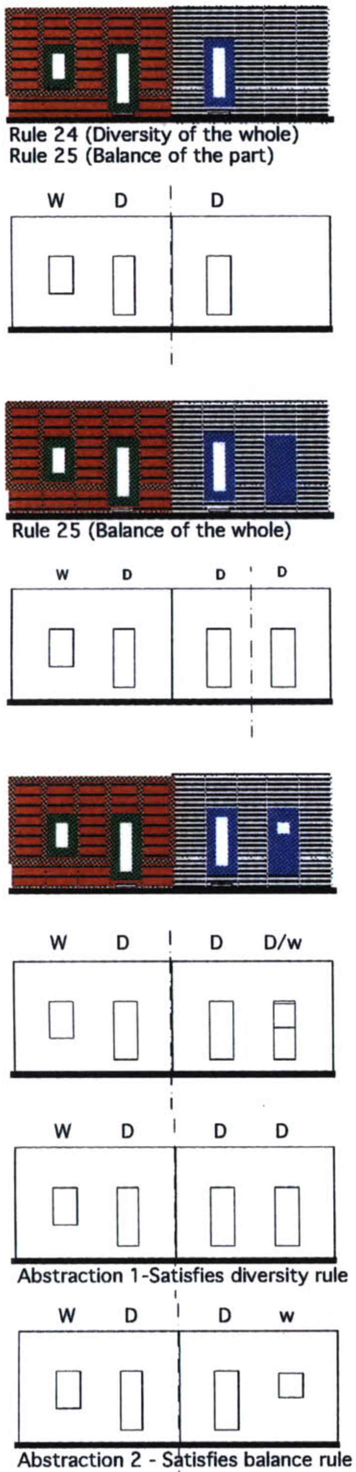


Fig. 7.66
Two opposed rules guided Ana's design process. Different kinds of abstraction allow different readings and so permit the satisfaction of both rules and the perception of an enhanced diversity

Ana's design process, also provides another interesting example of how conflict produces enhanced diversity. Ana's design was informed by conflicting rules: one aiming for order, and the other aiming for diversity. We saw how Ana started her design by defining a prototype that became her first house. However, when she had to design a second house she was confronted with a problem. She built the wall and for the sake of diversity, used a different color-pattern from the first house. After she built the wall she placed the door and, again, for the sake of diversity, she used a different color. However, when she was ready to place the window she realized that the design would become clearly symmetrical in terms of form (Fig. 7.66). And so, she decided to place a door instead. She could not place a glazed door because she had already used a glazed door, and so, for the sake of diversity, she placed an opaque door. However, she then perceived the design as out of balance, and so added a window to the door. By adding that window, she diminished the weight of the second door—balancing the composition, which resulted in two possible readings of the composition: in one she would read the door and perceive the composition as more diverse (abstraction 1), and in the second reading she would abstract the presence of the door and read only the window, and perceive the composition as symmetrical, and thus more ordered (abstraction 2).

In conclusion, the use of conflicting rules in the generation of a design causes design to become more ambiguous. Ambiguity allows multiple ways of seeing the design, leading to the perception of enhanced diversity.

7.2.15 Formal and Functional Wholes

Why did designers fail?

6

Designers (and non-designers) tended to treat their designs as a whole, and that prevented them from generating diverse designs

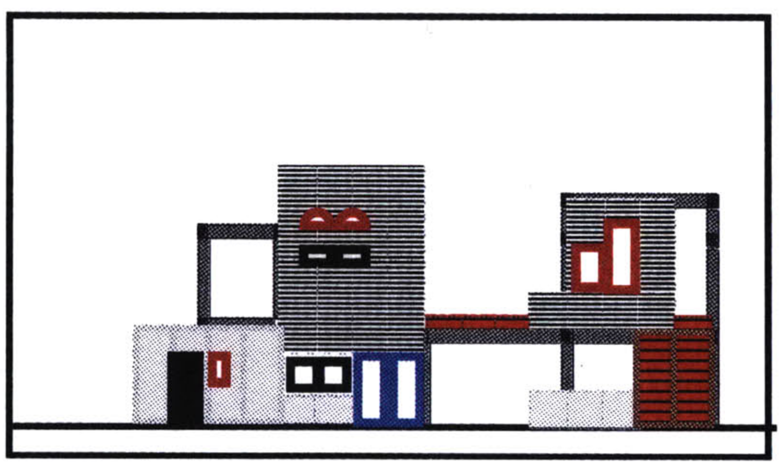
As explained in a previous chapter, the task assigned to the subjects in the "Spoken Game with Architectural Elements" was to design diverse facades out of the standard elements. However, the results show that all the subjects, except two, designed only one facade, despite being asked to design several facades. In this section, I will argue that this fact can be understood as a reflex of a larger behavioral pattern that leads subjects to treat their designs as a whole. I will then explain how this trend prevents subjects from generating diverse designs.

What factors affect the perception of diversity?

2

A correspondence between functional and formal parts and wholes enhances the perception of diversity

By looking at each design (Fig. 7.44), one will observe that all the designers seem to have generated a single building, except Ana whose design clearly looks like a row of houses. This is confirmed by reading the Verbal Protocol (Appendix B.3). In fact, Thomas, Wade, Salvatore, Ming and Pedro said they designed the facade of a house, but Taylor said he designed an art school, and Ana said she designed a group of houses. Joan said she had designed two houses but her design does not clearly look like two different houses, but rather a single one Fig. 7.67.



After correction

Fig. 7.67
Joan's design does not look like two different houses

It is interesting to explore why we do not perceive Joan's design as two houses since it will help us to lay down the argument of this section. In order for a design or a built artifact to be perceived as two houses, it has to have something that tells us that it constitutes two distinct entities. They can even look alike, but we will have to be able to say that they are two different houses, and not one. In other words, their visual appearance has to convey the message that they represent two functionally different entities. Joan's houses lack this attribute. It is true that once we know that they are two houses we find it plausible. However, the design is not absolutely clear about the fact. Why do we not immediately recognize that Joan's design is in fact two different houses? Firstly, they seem to share the central space. Secondly and more important, we do not see the door of the second house. The lack of the door leads us to the following reasoning: since our common sense tells us that nobody would build a space that nobody could enter, and since we do not see a door from the street to that space, we think that it might be accessible from other space which does have a door to the street. Our conclusion then is that the design does not represent two houses but one with two different spaces. In other words, because the form of Joan's design fails to provide a definitive visual clue that it is, in fact, two houses, we perceive it as a single house.

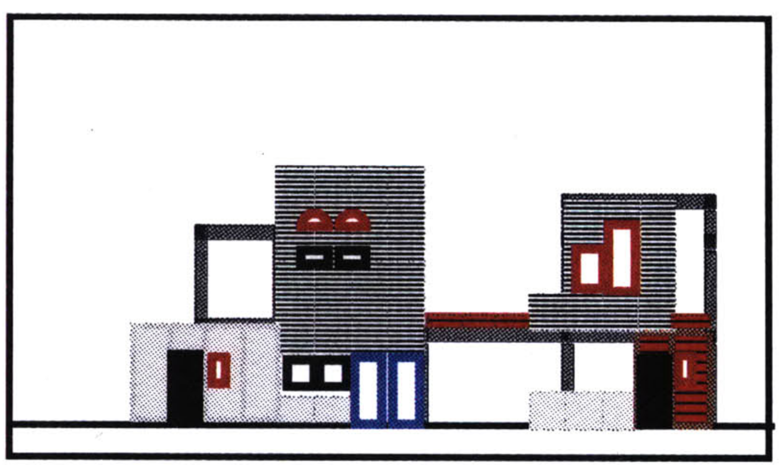


Fig. 7.68
Joan's design with a visible door on each house

In conclusion, all the subjects except Ana designed what one perceives as a single building. A building, as we know, constitutes a functional unit. Therefore, the fact that the subjects designed the facade of a single building is a factor of functional uniformity, and so it also represents a step back from functional diversity. I argue that the perception of functional diversity is important for the perception of diversity in general. Look at Joan's design in Fig. 7.68 in which we introduced a door to the street on the second house. It certainly improves our ability to see the design as two different houses. Because the design is perceived as two different functional units it is functionally more diverse. I argue that because the design is functionally more diverse we perceive it as more diverse in general.

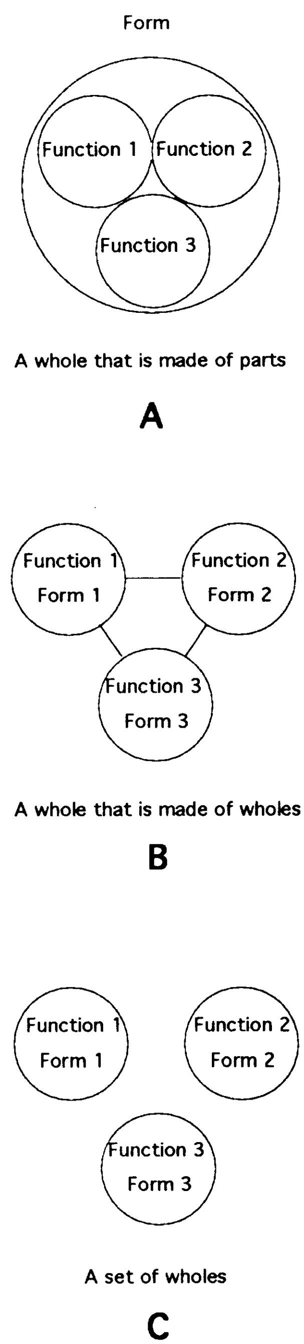


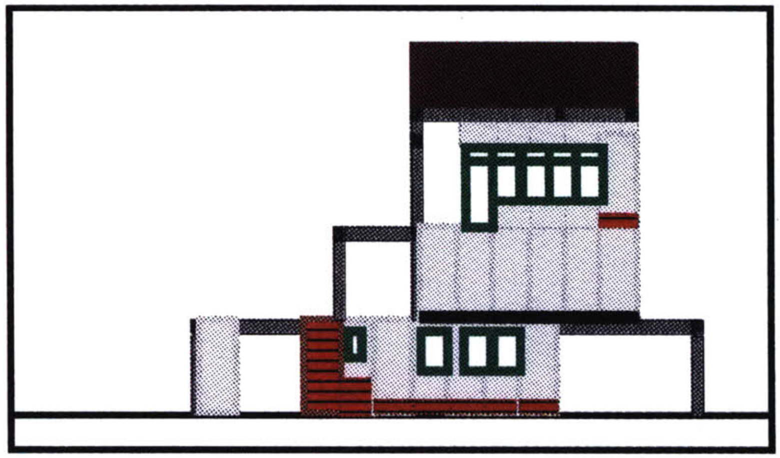
Fig. 7.69
Functional and formal parts and wholes

To think about a design or a built artifact in terms of parts and wholes will help us to explain my argument. For the present purposes, I will define a whole as something that is formally and functionally distinct. In other words, a whole can be physically isolated and still be able to perform its function. A whole is made of parts. A part can be a specific subform of the larger form that constitutes the whole, or a subfunction of the whole's function. A part only becomes a whole if it achieves a great formal and functional autonomy. Therefore, a whole with several parts does not necessarily constitute a group of wholes, as a group of wholes does not necessarily form a larger whole. In Fig. 7.69, A is a whole that is made of parts; because there is no correspondence between formal and functional parts, its formal parts are not functional wholes, and vice-versa. B is different. Because in B there is a correspondence between functional and formal parts, B constitutes a whole. However, in C despite the correspondence between functional and formal parts, the degree of autonomy of the parts became so great and the connections between the different wholes so loose, that the group of wholes does not constitute itself a whole. In conclusion, there are two different phenomena that are important in the classification of a part as a whole: one is the correspondence between functional and formal parts, and the other is the degree of autonomy of the parts from the whole.

The relationships between parts and wholes, or between smaller wholes and larger wholes are very subtle, and so is their influence on the perception of diversity. I argue that to be able to see that a whole is made of wholes improves our perception of diversity. Let me give an example to illustrate my argument. Think about a melody that comes out of a tape recorder. The tape recorder is our whole that is performing the function of emitting a melody. Now think about a group of singers that is singing in unison the same melody. Each singer is itself a whole. The group of singers is certainly more diverse than the tape recorder. I would even argue that our perception of diversity would increase if each singer sang just a specific part or sound of the melody, instead of the entire melody. On the other hand, a great autonomy of the smaller wholes might be perceived as disruptive and chaotic. In our group of singers, that would occur if each singer sang the melody at differed times or emitted sounds that did not have any connection. In this case the group of singers would not constitute a whole. In other words, a group of people singing does not necessarily form a choir.

Now that we are equipped with a terminology that facilitates my explanation (we can say for instance, that Joan's design was not perceived as two houses because we did not perceive it as two wholes), and that I have made my argument, a return to the analysis of the designs will help to define the architectural implications of treating designs as single wholes. Ming's and Ana's designs are suitable for this purpose.

Ming argued that his house was functionally diverse, since it accommodated different apartments, and spaces with different uses (Verbal Protocol, Appendix B.3). It certainly also has a certain degree of visual diversity (Fig. 7.70). However, his building is still one building, in which the different spaces or units



After finishing and correction

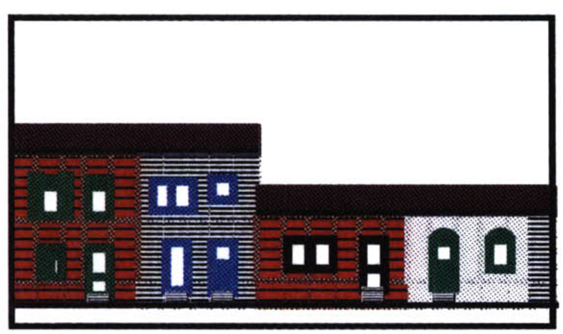
Fig. 7.70
The Ming's design functional diversity is not formally apparent

(the different porches, and apartments) are subordinated to the larger building. Functionally, some units like the apartments, have a fair degree of autonomy but share, nevertheless, some common spaces such as the entrance lobby and the stair case. Formally, these units do not constitute smaller wholes since they are not formally differentiated. The lack of a clear relationship between functional and spatial differentiation leads us to perceive the building as a whole made of parts that have less marked differences. Therefore, we would perceived it as less diverse than if it were made of more independent parts. We would say that it is a building containing several dwellings, and not a group of different dwellings.

Fig 7.71
The perception of diversity in Ana's design is different before anf after she added a roof

On the other hand, Ana's design (Fig. 7.71) clearly looks like a group of several dwellings. The clear correspondence

1 - After ninety seven moves



2 - After roof and correction

between formal units and functionally autonomous units in her design, leads us to perceive each of the houses in the row as a whole in itself. Her design is thus a group of several wholes. The degree of subordination of each house to the street is considerably smaller, but the street can still be perceived a larger whole. We cannot, however, refer to it as a single building. Nevertheless, even Ana did not totally escape from treating her composition as a formal whole. Look how she added a continuous roof and a continuous cornice to her design, as if she were embracing the entire design with a large gesture (Fig.7.71-1). Look also how that affected the diversity of her design and how it looks much less diverse after that gesture than before.

I believe that thinking about a design as a whole in which all the parts are clearly submitted to the general order of the design is a general behavior of designers. Let me present an example: Le Corbusier's housing development at Pessac—1921 (Fig. 7.72). In that development, Le Corbusier was concerned with the mass-production of housing and with issues like flexibility and diversity (Boudon, 1972). His solution was a design system that could not only generate houses with different layouts, but also different urban designs. He attained a fair variety of the house layouts, and even of the urban arrangements of the different

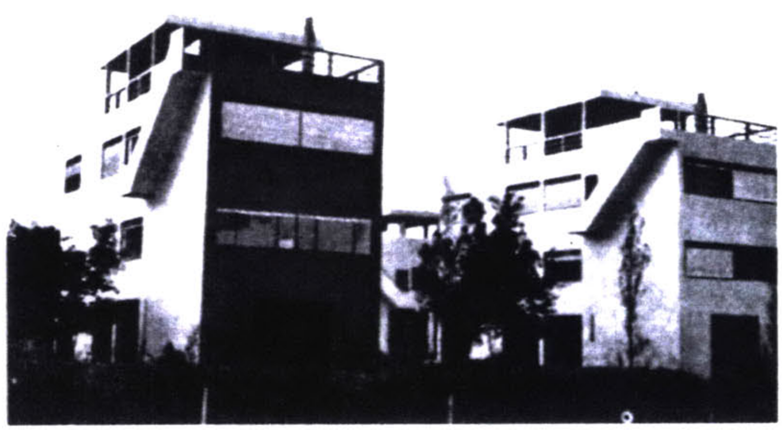


Fig. 7.72
Le Corbusier, 1921
Housing development at
Pessac, France

houses. He even extended his concern with diversity to the point of using a combination of different colors for the facades. However, he imposed strong restrictions on the other formal and aesthetical aspects of the facades, in order to illustrate his five points of architecture (wide windows, for instance). This restriction imposed on the entire development is somehow like Ana's roofs, it is a clear gesture with the intention of embracing the entire design and reducing it to the same order: Le Corbusier's order.

How can we explain designers tendency to treat their designs as a whole? I think that it is connected to their need for logic (as explained in section 7.2.11) that leads them to subordinate the entire design to a generative logical process. I also think that designers trend to treat the composition as a whole constitutes a symptom of individualism that has psychological mechanisms behind, connected to the expression of their own egos. As a result, architects express their egos by imposing a strong order to the whole artifact, and in such a way that the order of the whole is strongly imposed to order of the parts, and therefore, limit the degree of diversity of their works. In simpler words, they mirror their order in the order they impose to the designed artifacts in such a way that they limit diversity.

I will conclude this section by giving two more sets of examples that illustrate how the identification between formal and functional parts, and the degree of autonomy of the smaller wholes affect the perception of diversity. In addition these examples show how these relationships are considerably different in artifacts that are the work of a single individual than artifacts that represent the work of many individuals.

My first example is a comparison between Lucien Kroll's building "La même", a student dormitory for the university of Lovaina, Belgium (Fig. 7.73), and a street block from The Back Bay, a neighborhood in Boston (Fig. 7.74).

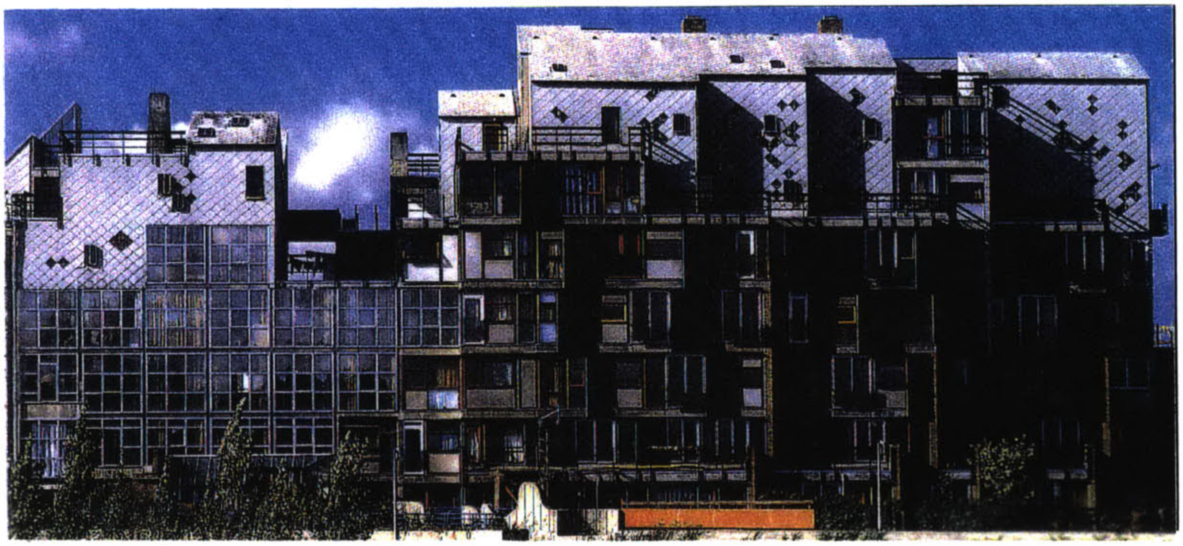


Fig. 7.73
Lucien Kroll, 1971
Sudent dormitory, University of Lovaina, Belgium

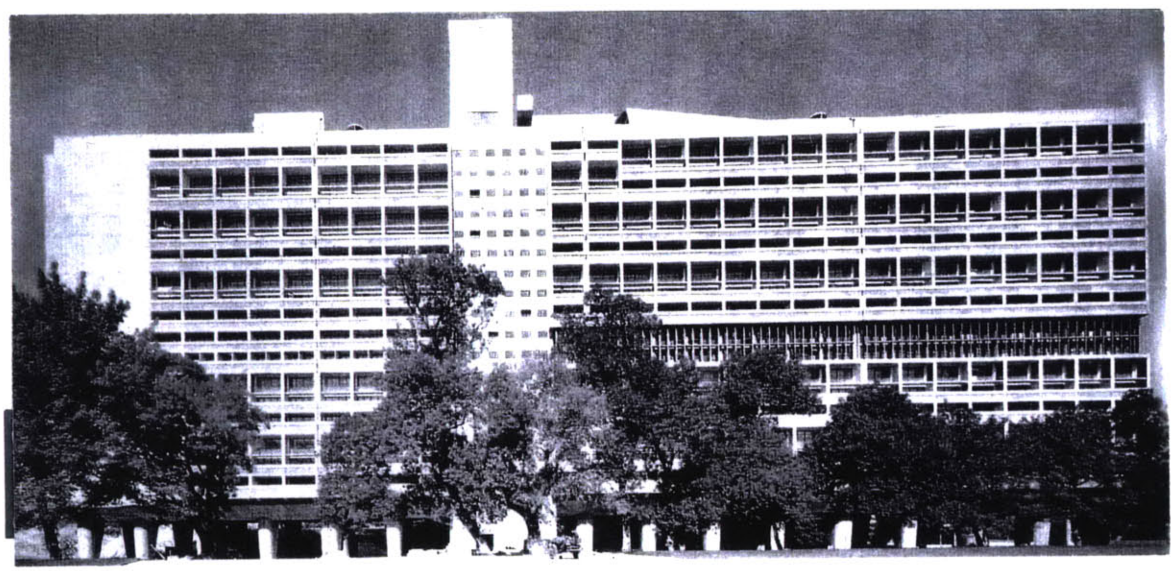
Fig. 7.74
The Back Bay, turn of century, Boston

In the dormitory, Kroll tried to express the individuality of the diverse students through its layout and facades. The building is visually more diverse than the Back Bay's block; it has more diverse colors, more varied window positions, more types of textures, and it is certainly more fragmented. On the other hand, the Back Bay's block is much more sober; its colors are similar, the position of the windows is more regular, brick and stone are the dominant textures, and it is much less fragmented. However, in The Back Bay's block, we can clearly perceive different functional part—the buildings, whereas in Kroll's building we perceive many small parts—walls and windows, but we do not perceive them as functionally autonomous. For us, Kroll's building, despite its visual diversity still constitutes a single building. I argue that we tend to perceive the Back Bay as more diverse because of the functional autonomy of its parts.

The second example is a comparison between one of Le Corbusier's *unités d'habitation* (Fig.7.75), and a group of houses from an informal settlement (Fig.7.76). In the Le Corbusier's *unité,* the different dwellings despite being functionally autonomous units, are functionally very subordinate, to the aesthetical and formal order of the entire building.

Fig. 7.75
Le Corbusier, 1945-52
Unité d'habitacion à Marseille, France

Fig. 7.76
Informal settlement, 1980s, Portugal



Independent of the aesthetical pleasure that one feels in contemplating the building, one also perceives a strong lack of diversity. In the informal settlement, each house constitutes a functional and formal unit, so different from the others, that our inability to understand its order leads us to perceive it as chaotic and unpleasant.

In conclusion, I referred above to what I think causes a designer's trend to treat designs as a whole. Additionally, I argued that because designers tend to frequently subordinate the parts of their design to that of the whole, there is not in a clear identity between formal and functional wholes in their designs. Because of this lack of identity, the designs are not perceived as being composed of distinct elements, and so they are not perceived as diverse as they could be. The consequences of this lack of architectural diversity increase when associated with other design factors such as scale. These consequences will be addressed in the next section.

7.2.16 Scale

Why did designers fail?

7

The tendency to limit diversity at the design scale, prevented designers from generating diverse designs

We saw in Section 7.2.8 how the design medium influences the design process. Additionally, we will see how that influence, together with the influence of scale affects the perception of diversity, preventing designers from generating diverse designs.

What factors affect the perception of diversity?

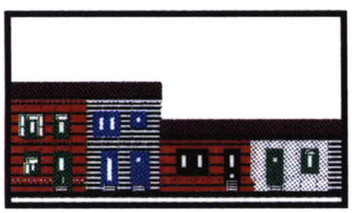
3

Scale affects the perception of diversity

When designers restrict the number of diverse elements they could use in their designs by reducing the occupied area of the drawing board to only a certain portion of the overall area (Section 7.2.10), they let the design medium affect the evolution of their design processes. This behavior suggests that for designers, design artifacts become the goals of their design processes, more than the building artifacts they represent. Consequently, designers tend to measure diversity by measuring the designs' diversity, forgetting that the design is a reduced virtual model of the real building. If they do so, because at the design scale designers do not tolerate more than a certain degree of diversity (Section 7.2.9), when the design artifact becomes a built artifact, it becomes necessarily less diverse; the area increases, but the number of different elements and color-patterns remains the same.

This phenomenon can even be perceived if we up scale a given drawing (Fig. 7.77); the bigger drawing looks less diverse than its smaller version. Unless, the scale is so small that it makes

Fig. 7.77
Scales influences the perception of diversity. All the drawings are similar, but a bigger one (bottom) looks less diverse than a smaller one (right), except if it is very small



hard to perceive the different elements and color patterns that constitutes the drawing. Additionally, if a drawing is considerably up scalle, an observer will be able to see only a part of it, since the rest falls out of his field of vision . Therefore, the number of different elements and color-patterns in that area is smaller, and thus the portion of the drawing that is seen is less diverse than the total drawing. The influence of scale in the perception of diversity is diagrammed in Figs. 7.78 and 7.79.

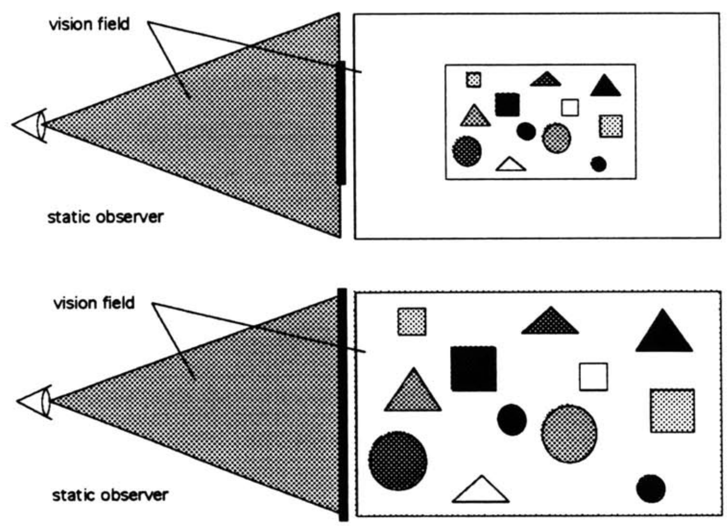


Fig. 7.78
Scale affects the perception of diversity. The drawings are similar, but the observer sees the same number of different elements within a larger area in the bigger drawing, thus perceiving it as less diverse than the smaller one

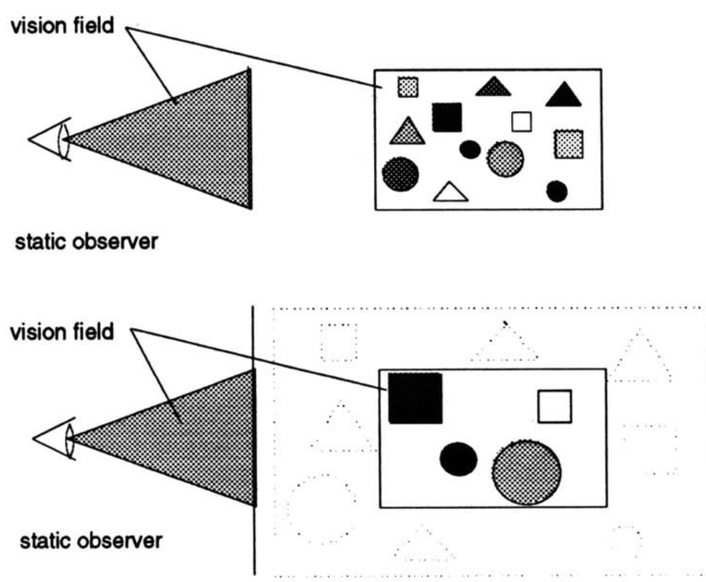


Figure 7.79
Scale affects the perception of diversity. The drawings are similar, but the observer is able to see only part of the bigger drawing, seeing fewer number of visible different elements within the same area, thus perceiving it as less diverse than the smaller one

The experiments also provided some direct evidence of how scale affects diversity. Taylor's judgment of Wade's design, for instance, is very meaningful in this respect. We saw that when Taylor was replying to Wade's design, he lost the sense of scale because the printed image of Wade's drawing was bigger than the computer screen. As a result, he did not perceive Wade's design as diverse at all:

> *T: How come that building looks so much bigger than mine can possibly be?*
> *You want diversity right? That building isn't very diverse.*

And he also did not perceive the design as a house, as Wade intended, but as a big building:

> *T: (...) I couldn't imagine being here, unless I was in a mall market, or some very large discount store which don't have any windows. Which says to me. It's about as good as the [...] Cub around here.*

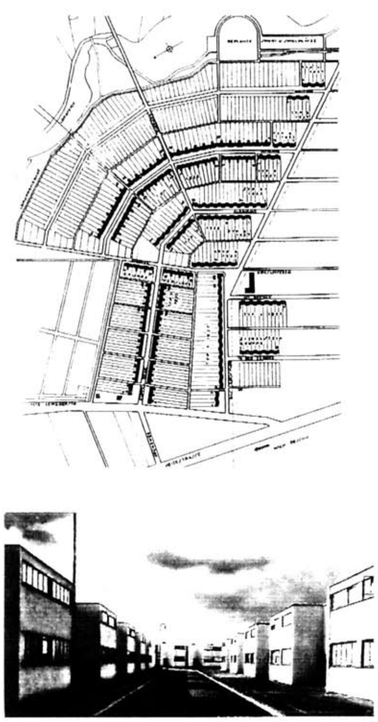


Fig. 7.80
Walter Gropius, 1928
Torten Housing development, Dessau, Germany
The traditional method of designing from large scales to small ones leads to the lack of architectural diversity

Scale is therefore, a main factor in the perception of diversity. Additionally, the gap between the scale of the design artifact, and the scale of the building artifact can constitute a major factor for the lack of architectural diversity in large edifices. If designers have to design a facade of a big building, or the facade of a cluster of buildings, and if they start their designs on a small scale, as they often do, the possibility of designing diverse facades is considerably restricted because designers cannot tolerate more than a certain degree of diversity at the small design scale. One can, thus, imagine the effect of such a phenomenon when the difference in scale between the original drawing or model and the final one is very high, like in the design of large housing developments.

As a corollary, the design medium has also an important role in this phenomenon, since it does not allow the representation of small details that could contribute to an enhanced diversity of the real architectural artifact. It can be certainly argued that as the designer progresses he moves from smaller to larger scales and so the design becomes increasingly more detailed. Nevertheless, when the designer moves from small to larger scales he is less able to have a complete external representation of the entire design, and he is also not able to build an internal description due to his memory constraints. Therefore, since he tends to treat the design artifact as a whole but cannot assess the whole, he is prevented from making changes in details from one part to another part of the design. As a result, the structures of the architectural artifacts designed in the traditional way become radically different from the structure of nature that has been described by fractals and chaos theory (Figs. 7.81). In objects with a fractal structure, like many natural objects, such as rocky mountains, animals, and trees, scale does not affect the level of detail, whereas in other objects, like some produced by humans, such as large planned architectural artifacts, it does (Fig. 7.80).

The problem of the lack of architectural detail beyond a certain scale in architectural artifacts also depends on architectural trends. The problem is more accute in modern architecture than in the architecture that existed before, where decoration had an important role in taking detail and complexity to small scales (Fig. 7.82). Modern architecture, on the contrary, eliminated decoration by reducing buildings to elementary forms. As Gleick points out in his book *Chaos: making a new science*:

> *Discontinuity, bursts of noise, Cantor dusts--phenomena like these had no place in the geometries of the past two thousand years. The shapes of classical geometry are lines and planes, circles and spheres, triangles and cones. They represent a powerful philosophy of platonic harmony. Euclid made them a geometry that lasted two millennia, the only geometry still that most people ever learn. Artists found an ideal beauty in them, Ptolomaic astronomers built a theory of the universe out of them. But for understanding complexity, they turn out to be the wrong kind of abstraction. (Gleick 1987)*

Fractals theory might provide a valid paradigm to re-analyze the structure of man-designed objects where scale is a major factor such as large housing developments. Namely, it might help to understand why these artifacts constitute a failure when considered in terms of diversity. We will address scale again when adressing order, and come back to the idea of a fractal structure at the end of this thesis.

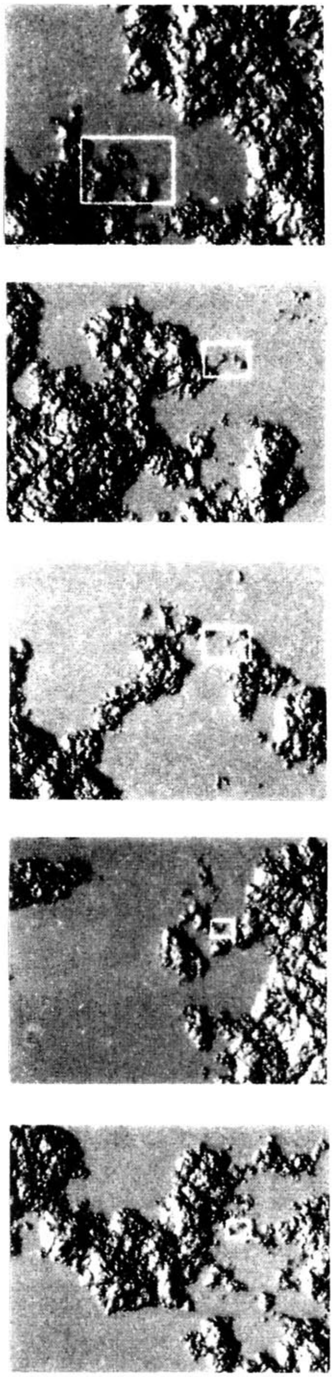
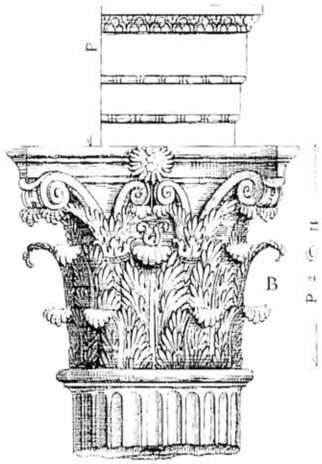


Fig. 7.81
A fractal shore. A computer-generated coastline: the degree of roughness or irregularity looks the same no matter how much the image is magnified (image R. F.Voss reproduced in (Gleick,1987)



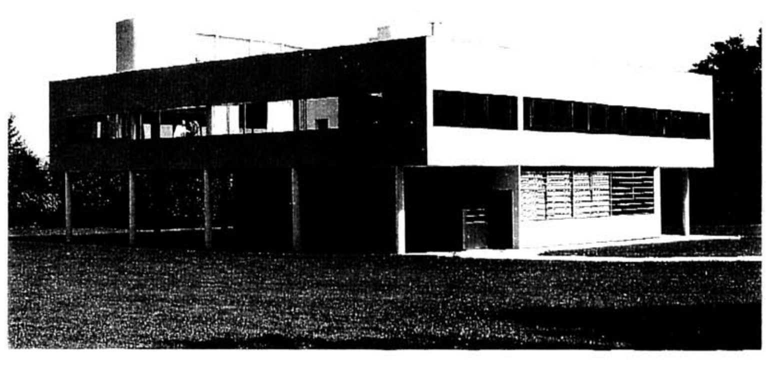


Fig. 7.82
Palladio, 1550, Logia del Capiatanato, Vicenza, Italy (top)
Gaudi, 1905-07, Casa Batló, Barcelona, Spain
Le Corbusier, 1928-31, Villa Savoie, France (bottom)

Sharp contrast between other styles and modern architecture, which eliminated detail, reducing complexity and diversity.

7.2.17 Distance, Motion, and 3 Dimensions

Why did designers fail?

9

The design media prevented designers from accurately assessing how scale, motion,and 3 D affect the perception of diversity

In the previous section, we saw that scale is a major factor affecting the perception of diversity, and that as a consequence, the way people perceive diversity in a design is different from the way people perceive diversity within a built space. In this section, we will see how other factors such as distance, motion, and the existence of three dimensions also affect the perception of diversity and increase the discrepancy between design and reality, causing designers to create less diverse artifacts.

Distance

As an immediate consequence of the fact that scale affects the perception of diversity, we have that the distance of the observer to the object he is looking at also affects that perception. If we step back from an object the object looks smaller, whereas if we come closer to it, it looks bigger. As we move away from an object, we lose the capacity to perceive the difference in its smaller details, and so the object will look less diverse, unless if it is so big that by stepping back we will be able to see parts of it that we were not able to see before, assuming that those parts vary from the ones we saw before. If they don't vary we will perceive the object as more and more monotonous. The influence of distance in the perception of diversity is diagrammed in Fig. 7.83. An analysis of that picture will help to understand the effect of such influence. For the observer the angle of vision is constant (A). So, as distance increases the field of vision increases as well, and objects look smaller (B). If an observer is located close to a big object he is able to see only a part of that object (1). If he is located at a distance from which he is able to see the entire object within his field of vision, the object looks smaller and he is able to see new details, and thus, perceives the object more diverse than before (2). If he is located even further away, he sees the object even smaller, and because he sees the same details within what he perceives as a smaller area, he perceives the object as more diverse again (3).

What factors affect the perception of diversity?

4

Distance, motion, 3D, and surprise affect the perception of diversity

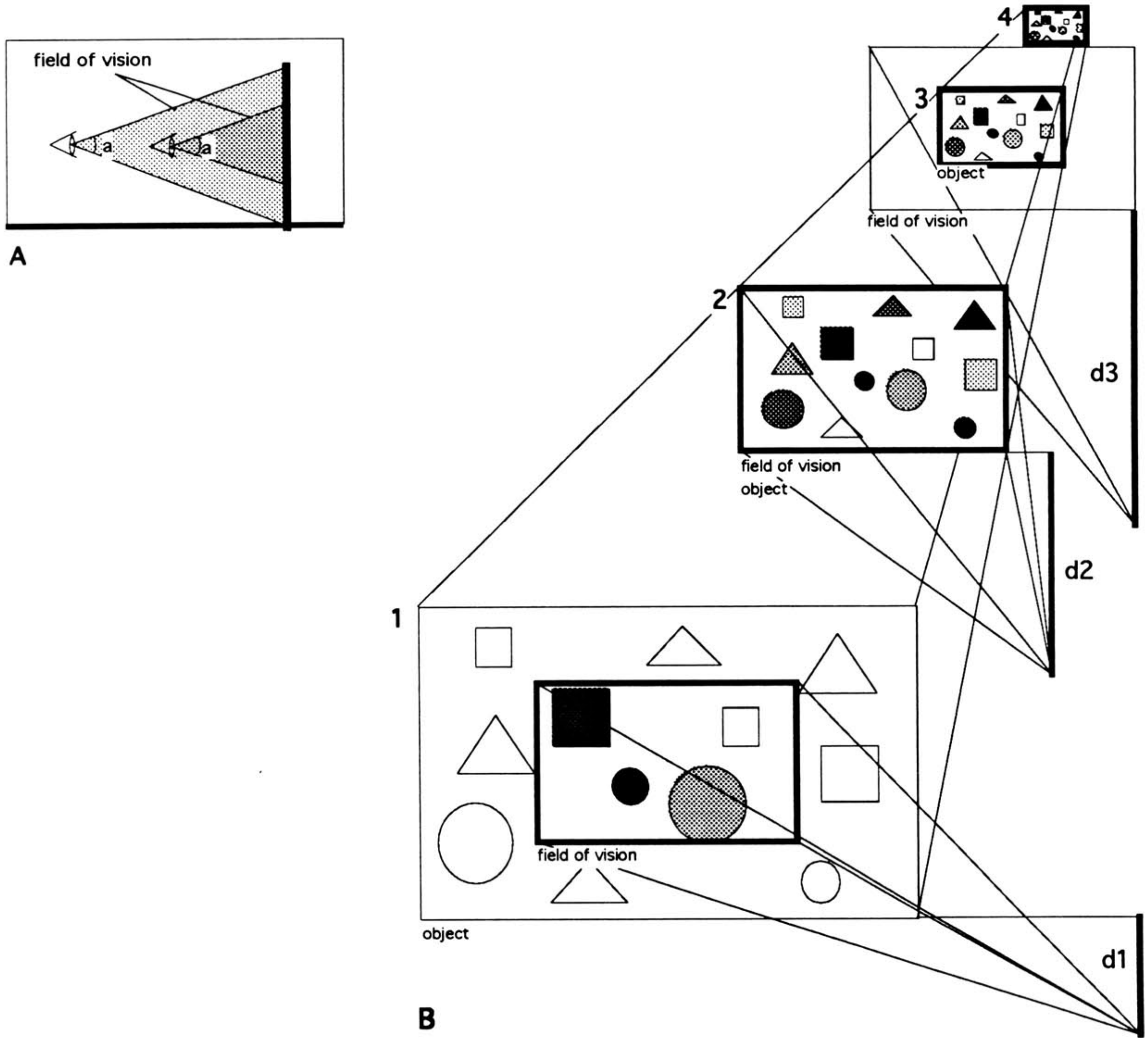


Fig. 7.83
Distance affects the perception of diversity (see text for explanation)

However, if his distance to the object continues to increase, beyond a certain distance, he loses the capacity to perceive significant differences in detail and perceives the object as less diverse (4). In summary, distance affects the perception of diversity in a non-linear way.

The influence of distance on the perception of diversity of a built environment is considerable. I have a story that might help us to understand this influence. One day I was commenting on the diversity of the Back Bay—the neighborhood in Boston where I live. My friend on the other side of the Charles river, from whose apartment the Back Bay from whose apartment the Back

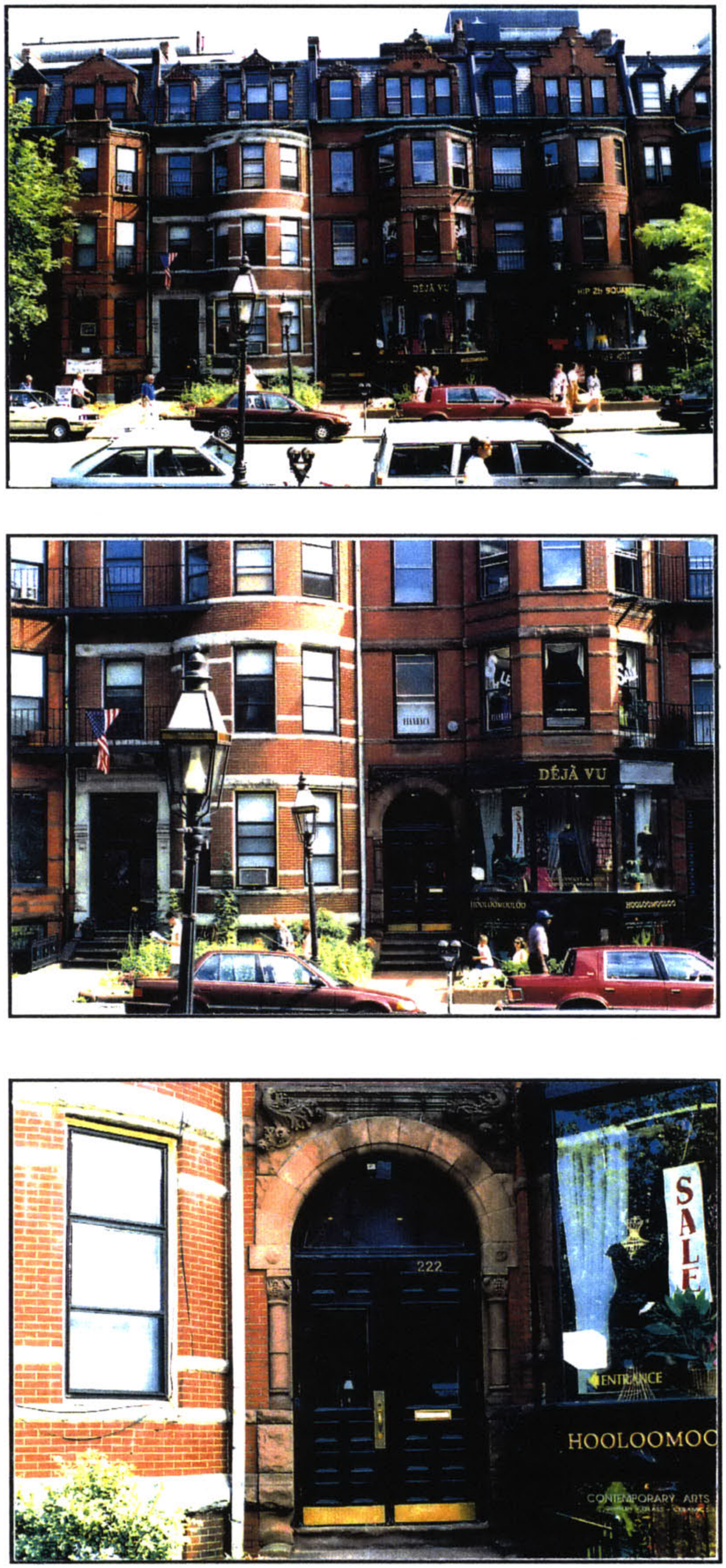
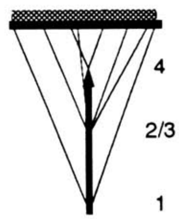


Fig. 7.84
Distance influences the perception of diversity in a urban environment. As the observer approaches urban artifacts, he is able to see new details, and so the perception of diversity reaches another level. The Back Bay, Boston, USA: a group of buildings (a), a building (b), and details (c)



Trajectory of the observer

Bay can be seen, seemed surprised and said: "Back Bay? Diverse? But it is just a group of brick buildings." Obviously, for him my neighborhood did not seem diverse since from his apartment it really looked like a diffuse group of brick buildings. For me, a Back Bay resident, it looked diverse. From the window of my apartment, or in walks in the neighborhood, I was able to see different colors and windows, the variations in the height and size of the bow-windows, and so on; differences which my friend could not see. The influence of distance on the perception of diversity in architectural artifacts is illustrated in Fig. 7.84.

Motion

A direct consequence of the influence of scale and distance on the perception of the diversity of a certain object, is the fact that it matters if the observer is or is not in movement when he is looking at the object. When the observer moves, he changes his field of vision, changing his perception of the object. Basically, the observer can have two different types of movement: he can move himself in the space, changing his location constantly, or he can simply turn his head around or nod up and down. Each movement influences the perception of diversity. These influences are diagrammed in Fig. 85. The observer is initially located at a distance from which he sees the entire object and is able to distinguish its details (1). As he starts moving, the size of the object in his visual field increases until he is able to see only a part of it (2). If the object is diverse, it will look less diverse. Our observer then stops and turns his head around towards a different part of the object. If the object is not homogeneous, he will see a different part of it, and perceive the diversity of the object. For an object perpendicular to the trajectory of the observer, the effect of a slight turn of the observer's head is roughly similar to the effect caused by taking a step sideways; the virtual scale of the object does not change. Our observer decides continues his walk towards the object. He will see then the details of the object bigger and perceive the object as less diverse. The influence of motion on the perception of diversity in architectural artifacts is shown in Fig.7.86.

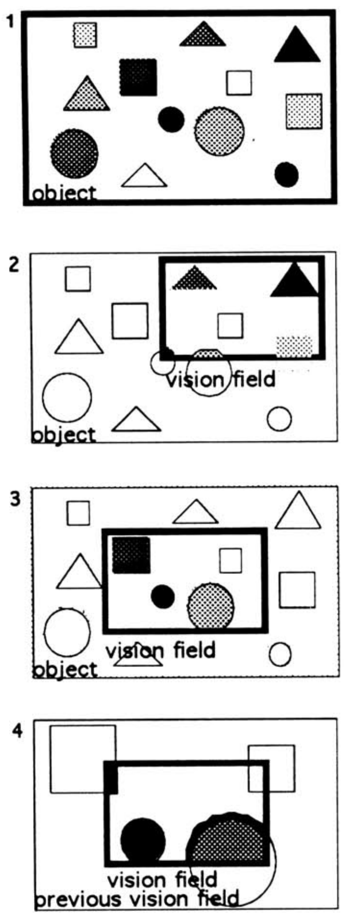


Fig. 7.85
Motion affetcs the perception of diversity

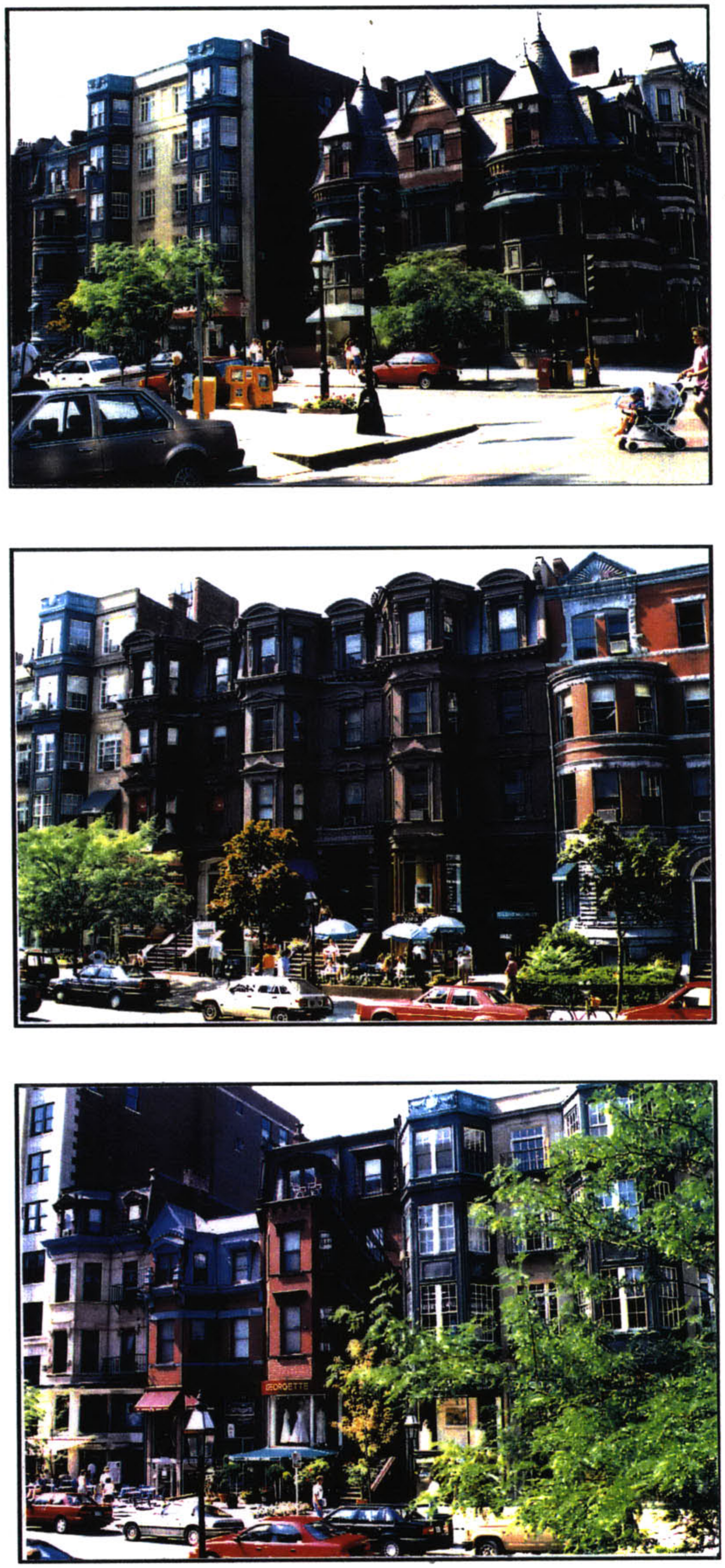


Fig. 7.86
Motion affects the perception of diversity in a urban environment. As the observer moves along a street he sees new artifacts, which can be similar or diverse from previous ones, and so influence his perception of diversity
The Back Bay, Boston, USA

Three dimensions

Another and obvious factor that affects the perception of diversity, and that differs from design to reality is the existence of three dimensions in reality compared to two dimensions found in design. The existence of three dimensions together with the fact that the observer is in motion contributes to make each view of the object unique. In this way, the three dimensions of the object, contribute to make the object more diverse than the design. However, the effect of the existence of three dimensions, even with the use of models, is hard to judge due to the difference in scale between the design and the object itself. Moreover, due to the difficulty of representing and assessing elaborated 3D artifacts, designers might tend to create buildings whose facades are mere extrusions of their 3D representations. Doing so, they decrease the possibility of designing diverse facades. The experiments provided one explicit example of how the use of a 2D design medium constraints the design process. When Taylor was designing at a certain point he asked:

> T: As I am working on this since I started to clad it... It is very easy for me to take a [...] approach doing that. Do you want me actually to think about it as if I am cladding a plane surface of a concrete surface, or can I kind of use these different colors and different shapes to suggest relief?

The question shows how difficult was for Taylor to create a 3D artifact using a 2D design medium. The influence of 3D on the perception of diversity in architectural artifacts is illustrated in Fig. 7.88.

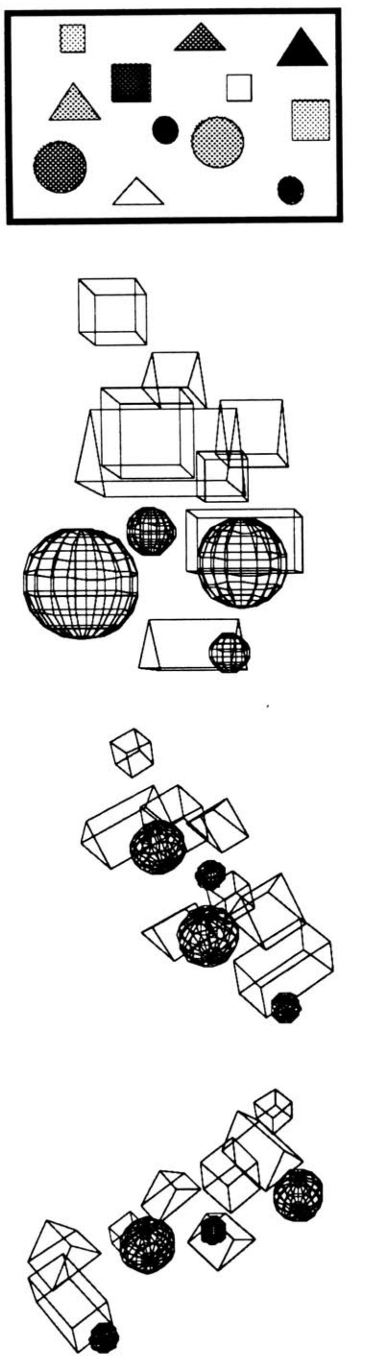


Fig. 7.87
Since each view of a 3D object is unique, the existence of three dimensions contributes to the perception of an enhanced diversity

In conclusion, the perception of the diversity of an object is not only affected by scale, but also by the distance between observer and object, by the possibility of movement of the observer, and by the number of dimensions of the object. The fact that these factors vary between designed and built objects causes the perception of diversity in design to be necessarily different from the perception of diversity in architectural objects. The effect is such that designed objects tend to look more diverse than the built objects they represent. Therefore, the design media prevents designers from creating diverse artifacts.

Fig. 7.88
Influence of 3D on the perception of diversity. The facades which are not the result of simple extrusion of a 2D drawing are more successful in terms of using three dimensions to enhance the perception of diversity. Building on Mass. Ave. (top), and buildings in Back Bay, Boston, USA

7.2.18 Repetition and Surprise

Why did designers fail?

1 0

The design media prevented designers from accurately assessing how repetition and surprise affect the perception of diversity
What factors affect the perception of diversity?

5

Repetition and surprise are an element of diversity

There is one significant consequence of the influence of scale, distance and movement, on the perception of diversity that also constitutes a significant difference between designed and built objects. Consider that the built object is so large and is placed in such a way that it cannot be seen all at once, but only by moving around it or along the space that it bounds. The perception of diversity might be given by an unexpected change in one or more of the attributes of a repeated part of the object. Consider, for instance, that the object is a street. In this case the perception of diversity could be given by a change in details from window to window, or a change in windows, from house to house. These changes cause an effect of surprise that, thus, constitutes an additional factor involved in the perception of diversity.

The acknowledgment of this fact has an interesting outcome: in order to be surprised there has to be repetition, therefore repetition can be an element of diversity. Moreover, when variation becomes constant it becomes predictable, therefore repetition is indeed a required element of diversity. The experimental results support this conclusion. In fact, the designs that were considered diverse by the subjects who designed them, are also among the designs that exhibit high degrees of element and color repetition, as shown in following.

I define degree of element repetition in a design as the ration between the total number of visible elements, and the number of kinds of elements used in the design. The degree of color repetition is defined in a similar way. Both the degree of element repetition, and the degree of color repetition in the designs of the "Spoken Game with Architectural Elements" are shown in Table B.XI. The analysis of this table shows that Ana's and Pedro's designs are among the designs that exhibited high degrees of repetition. Since both Ana and Pedro considered their designs as diverse, unlike all the other subjects, we can support the argument that repetition is an element of diversity. In the following section we will see how repetition is also an element of order, and discuss the role of repetition in the achievement of ordered and diverse facades.

7.2.19 Order

Why designers failed?

1 1

Designers (and non-designers) exhibited a trend towards order which prevented them from generating diverse designs

In the discussion of the results of "The Spoken Game with Abstract Elements", we showed that when asked to generate diversity the subjects exhibited a trend towards order, interpreted mainly as balance. In this section, we will see that the subjects of the "Spoken Game with Architectural Elements" not only exhibited a similar trend, but also trends towards other types of order. The results of both experiments seem, thus, to support the hypothesis that there is a general trend towards order.

How order is perceived?

1

Orderliness, logic order, and balance

Order and diversity are two different aspects of one unique entity

I argue that this trend prevents designers from generating more diverse designs. I do not mean that diversity is incompatible with order, but only that diversity makes the achievement of order more difficult. For instance, when Thomas, who also was a subject in experiment A, was asked to design facades that were diverse, he designed something that resembled his first experiment—a structure and an infill of diverse elements—and the meaning of which is not clear architecturally (Fig. 7.89-a). His design looks merely like a composition with architectural elements, rather than the representation of a building. When we insisted that his design should have a clear

Fig. 7.89
Thomas' designs with architectural elements: first attemp (a), and second attempt, (b)

architectural meaning and asked him to repeat the experiment, he designed a house which did not look diverse at all (Fig. 7.89-b). When asked if he considered his design diverse, he said:

I completely forgot about diversity.

What I think is important to note is the apparent conflict between the requirement of diversity and the need to make something ordered in such a way that it looked like a building. Architecture seems to require order. As mentioned above, the results of the "Spoken Game with Architectural Elements" confirm that balance is one important type of order, and suggest the existence of at least two other types of order: orderliness, and another that I will call logic order . We will address each type of order—orderliness, logic order, and balance—separately.

7.2.19.1 - Orderliness

How order is perceived?

1.1

Orderliness: designers (and non-designers) considered orderliness a requirment of their designs

Repetition is an element of orderliness, and thus, is also an element of order

Repetition is an element of diversity and order

Variation-repetition as unique feature of Diversity-orderliness

A method of measuring diversity-orderliness: Degree of Repetition

Orderliness is frequently referred to in architectural treatises and is probably the most broadly accepted concept of order. According to the Webster's dictionary, orderliness is related to regularity, or to regular sequences of objects. Experiment B provided some examples of orderliness. I will refer to some of these examples in order to illustrate: (1) how orderliness is considered both by designers and by non-designers as a required feature of architectural designs, and (2) how repetition has a fundamental role in the perception of this type of order. I then argue that due to repetition, orderliness interferes easily with the requirement of diversity. Finally, I will try to relate orderliness and diversity through repetition in such a way that makes it possible to incorporate this relationship into a computer program as the street facade generator presented at the end of this thesis. For this purpose, I will use Ana's design since it was the one among those provided by the experiment that seemed more suitable, as I will explain later.

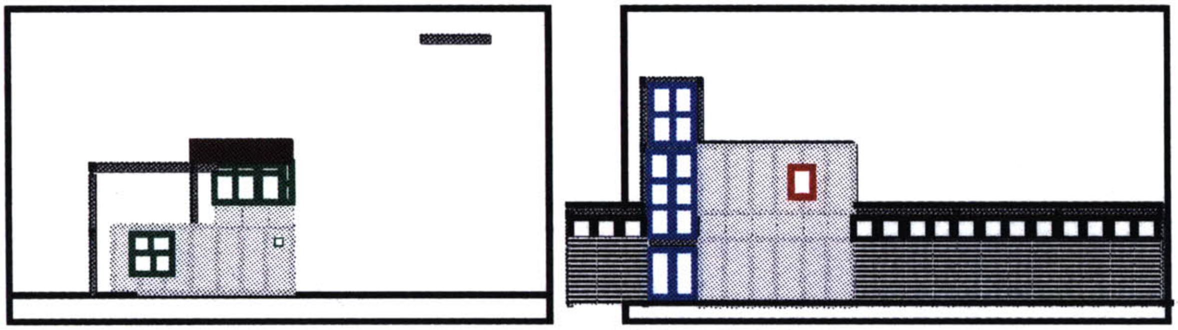
One clear example of concern with orderliness was provided by Thomas' second design (Fig. 7.89). After he said he had forgotten the requirement of diversity, he added:

> *Well, it is repeating those things to a certain degree but [it] doesn't fill up the whole structure. And then there is two open [spaces] for the structure to be exposed once completed, and this is completely clad, and the upper one is not completely clad, and the windows are different, but the same color, the same repetition, so you can find some diversity.*

In this statement Thomas was trying to show how diversity was present in his design, despite completely forgetting that requirement during his design process. The definition of diversity implicit in his statement is very similar to the definition of diversity he gave in the "Spoken Game with Abstract Elements", which was the existence of a "a majority and then small minorities" (Thomas' Verbal Protocol, Appendix A.2). However, if in his own opinion, Thomas successfully achieved diversity in the first experiment with abstract elements, he did not achieve that in the second one when he had to use architectural elements to produce a facade, even after a second attempt. Implicit in Thomas' diversity rule is that only when he perceived a fair degree of repetition could he consider interrupting it. In other words, he could only disrespect a rule once it was established. This observation confirms the idea, presented in Section 7.2.18, that repetition is an essential feature of diversity. However, it seems that in the "Spoken Game with Architectural Elements," he took repetition too far.

I argue that the difficulty of finding the right equilibrium between repetition and exception is what makes it so difficult to combine orderliness and diversity. I would even argue that this difficulty is such that it turns orderliness into the most difficult type of order that can be achieved.

This idea is supported by Salvatore's answer when we were discussing the diversity of his design. Salvatore justified



1 - Salvatore's design

2 - Taylor's design

Fig. 7.90
Salvatore and Taylor were more successful in avoiding symmetry than orderliness

the lack of diversity of his design with the few number of elements provided for the experiment:

> *S: We are so much concentrated in the elements that we forget to think diverse, because, when you say you have to design a facade with these elements we just think the elements are not so many so we think: 'what can we do with these few elements?' My problem, and, psychologically we refuse the issue of diversity...*
>
> *J: But you could have selected black windows, for instance, to put here. They didn't all have to be green. You have four colors for the windows.*
>
> *S: Yes. This is a kind of... I like a kind of order, this doesn't mean symmetry. But I really dislike having all these windows with all different colors.*

By looking at Salvatore's design Fig. 7.90-1, we can see that he was successful in avoiding symmetry but he was not so successful in avoiding orderliness. The same feature is found in Taylor's design (Fig.7.90-2). The sense of order in Taylor's design seems to be great but his design is certainly not symmetrical. The facts seem to suggest that in an attempt to produce a diverse design it is easier to avoid symmetry, than orderliness. Therefore, both designs support the idea that due to repetition, orderliness is the type of order that is more difficult to achieve in a struggle for diversity.

However, that does not mean that orderliness and diversity are incompatible with each other. Ana, for instance, was able to achieve a fair balance between the two features. I will first show how she was concerned with orderliness, and how she perceived orderliness from the diversity viewpoint. Ana's concern for orderliness was very clear, she said:

> *But this house... wait... diversity... anyhow, I cannot forget that I am drawing houses, therefore, diversity cannot be so, so big. There must be a minimum. I mean, I think that in a facade I shouldn't mix doors of different colors. Even in the same street, I think that there should be some codes, imposed.*

She continued her design, and later on, she said again:

> *Well, diversity, it has to be a certain coherence, glass doors, well the environment requires light and so the people prefer glass doors, unless they are very private. Diversity has limits. In the same house I am not going to paint the windows with different colors. I know I am very conservative, but...*

In her statements, Ana reveals that she perceived orderliness as a bad feature from the diversity viewpoint, but that at the same type she felt that orderliness was a good feature in her design, and in architecture in general. It seems that orderliness was something she needed to see in her design in order to feel comfortable with it. In fact, it seems that she was trying to maintain her design on the delicate border where it was neither too diverse, nor too orderly.

I base my statement that Ana achieved a fair balance between orderliness and diversity on the fact that she was the only one among the subjects who claimed to generate diverse designs that achieved some functional variety and orderliness at the same time. Recall that among all the subjects only June, Pedro, and Ana maintained that they had generated diverse designs. I explained in Section 7.2.15, that the lack of correspondence between functional and formal wholes in June's design and the total absence of functional variety in Pedro's diminishes considerably our perception of their designs as diverse, despite the formal diversity they present. On the other hand, Ana was able to achieve not only some diversity, but she also used repetition as an essential feature of her design. There are several examples of repetition in her design: she designed several houses, she followed the same housing type each time she designed a house, she used the same color for the different windows and doors of each house, and so on. Since the degree of element repetition is, in fact, considerable in her design (Table B.XI), and since she acknowledged herself that she required repetition in order to make her design look ordered, we can regard her design as orderly as well as diverse.

Once we admit that Ana's design is orderly and diverse, we have reason to be interested in the way she achieved that balance. We will, therefore, use her design to develop a mathematical way of measuring orderliness, using repetition. However, before doing so, I will introduce some concepts and propose methof of describing a facade.

a) Defining concepts. Towards a mathematical definition of derliness and diversity

Attribute and value

Fig. 7.91
Three big green squares

Look at shape A shown in Fig. 7.91-A. If we are asked to describe it, we say that it is a big green square. In doing so, we described shape A by describing its features. These features are *attributes*. Thus, we described shape A by giving *values* to its attributes such as green to color. Color is then an attribute that takes the value green in shape A. In our description of shape A as a big green square, the other attributes we used were shape and size, which, respectively, took the values square, and big. In fact, size is an attribute which is a function of two other attributes; those of height and width, and so it can be braken down into these atributes. In a similar way, color can also de decomposed into hue, saturation, brightness, weight and hotness. The use of composite attributes or elemental ones, depends on our need to define a given element[3], or to distinguish it from others in a given set. When an element is complex, or when it is very similar to others in a set, it might be necessary to use elemental attributes.

[3]In order to distinguish between the use of the term shape to refer to attribute, and the use of the term shape to refer to a distinctive element, I use element in the second case to mean shape.

For instance to distinguish element A from elements B and C in Fig. 7.91, it is necessary to be more specific about their colors, since all of them are green. We can distinguish their colors using, for instance, their hue values. Additionally, it might also be required or useful to define other attributes such as texture, orientation, proportion, and so forth. The list of some attributes that can immediately be defined for elements—that I would call basic attributes—are shown in Table I.

Table I
Basic attributes

	Attribute	Elemental attributes
s	shape	-
c	color	hue saturation brightness weight heat
p	position	(x,y)
h	height	-
	width	-
p	proportion	h / w
a	area (size)	h / w
	etc...	

Sometimes we can even combine composite attributes into new ones. For instance, if all the elements are vertical rectangles like Thomas's framework in experiment A, we can generalize and say that their shape is a vertical rectangle.

Qualitative and quantitative values

The values of attributes can be *quantitative* or *qualitative*. For instance, we can say that the orientation of a given rectangle is vertical or say that it is 90^{o}. The use of qualitative or quantitative values greatly depends on the variation of the values existing in a set of shapes, and on our interest in measuring that variation. If we need to measure the effective variation we should use quantitative values. If we only need to know whether or not there was variation, qualitative values are sufficient.

Sequences

Look at the set of elements shown in Fig. 7.92. If we are asked to compare the values of the attributes of all the elements in the set, we would have to decide which order to follow. We could use any order, but I argue that it would facilitate description if we break down the set into *horizontal sequences*. Other directions could be considered but I have two specific reasons for using the horizontal sequences. First, many of the subjects of experiment B built their design from left to right in a horizontal fashion. Most clearly, Ana followed this procedure in her design process, using the first house as a reference, as shown in Section 7.2.11. Second, I argue that it also is in a horizontal sequence that we look at buildings on a street. Since, this study

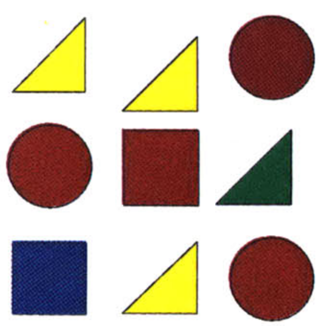


Fig.7.92
A set of elements

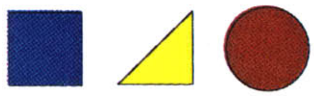


Fig. 7.93
First horizontal sequence of the set in Fig.7.93

is concerned with the design of street facades, it is appropriate to use horizontal sequences.

By using sequences, attributes and values, we are able to compare and analize the elements that constitute a given set. Table II shows the attributes and their sequence of values from the first horizontal sequence (Fig. 7.93).

Table II
Attributes and values of the sequence in Fig. xx

Sequence	Attribute Element	Values		
		1	2	3
1	shape	triangle	square	circle
2	color	blue	yellow	red
3	height	1m	1m	1m
4	width	1m	1m	1m
5	proportion	1	1	1
etc...				

In addition to horizontal sequences, *vertical sequences* can also be considered. Ana, for instance, used also vertical sequences in her design process, as can be confirmed by looking at the diagram in Fig. 7.42. For instance, when she designed the window of the second floor of her first house by comparing it with the window below, she designed it differently because she considered the vertical sequence. Therefore, we propose a method of comparing the various elements in a design, based on the way the subjects, especially Ana, designed and evaluated their facades. The method breaks down the design into horizontal na dvertical sequences, and is suitable for describing a street facade.

Variation

Attribute variation: qualitative and quantitative variation

We are now prepared to introduce the concept of variation. We shall distinguish between attribute variation, and sequence variation. *Attribute Variation* is the difference in value of a given attribute from shape to shape in a sequence. We can

Table III
Qualitative and quantitative variation of the sequence in Fig.7.93

Attribute	Color	
	1 / 2	2 /3
Qualitative variation	yes	yes
Quantitativ e variation	32768	5461 3

measure variation in two different ways. First, we can simply verify whether or not variation occurred—*qualitative variation.* Second, we can measure how much variation there was by measuring the difference between quantitative attributes—*quantitative variation.* Table III shows the qualitative and the quantiative variation from the first horizontal sequence (Fig. 7.93). I believe that the perception of attribute variation depends both on qualitative and quantitative variation. Additionally, I believe that it also depends on the difference between the maximal and the minimal values of a given attribute in a sequence—the *range of variation.*

Actual and perceived variation

Small differences between the values of attributes might not be perceived, and so in such cases there is no qualitative variation. Thus, we have to distinguish between *actual* and *perceived variation.* The minimal difference between the values of an attribute in order to be perceived as a variation can only be experimentally determined. Due to the time frame of this study, such experiments were not done, and so they have to be done in the future. The negative impact of the lack of these experiments was overcome in my study by using elements whose attribute values differ enough from element to element in order to be perceived as a variation.

To conform with the distinction between horizontal and vertical sequences, we must consider both vertical and horizontal variation.

Sequence variation

As seen above, in order to describe a set of elements from the variation viewpoint, we have to consider whether or not the values of a given attribute change from element to element. However, that is not enough to describe the arrangement. In order to accurately describe the arrangement, we also need to compare the qualitative variation of each attribute in a sequence with those of other attributes in the same sequence, or in other sequences. In other words, we have to compare the sequences, and by doing so, we are determining *sequence variation.*

Consider, for instance, that we intend to compare the attribute variation of the horizontal sequences of the set of elements in Fig. 7.92. We are faced with the problem of how to compare the sequence variation of different attributes. I propose to use the following method. First, we assign the letter *a* to the value of the attribute of the first element in the sequence, the letter *b* to the second element, and so on. Then, we repeat the procedure for all the other sequences. Table IV shows the result of applying such procedure to our set of elements using only the attributes shape and color.

Table IV
Sequences of attributes in Fig. xx

Sequence	**Attribute**	**Values**		
	Element	1	2	3
A	shape	a	b	c
A	color	a	b	c
A	shape	a	b	c
B	color	a	a	b
B	shape	a	a	b
B	color	a	a	b

Note that we did not substitute a specific value by a specific letter, since we are only interested in whether the value of a given attribute for a certain element in a sequence is different from that of the previous element. By looking at the table IV, we can, in fact, observe that the values of all the attributes sequentially vary in only two different ways, that is, 'a-b-c', and so we can characterize the sequence variation of the given set of elements as A and B. We could then apply the proposed procedure to the vertical sequences. Once that is done, we can to characterize the given set in terms of all variations. The method is already described.

Repetition
Repetition-variation

As opposed to variation, when two different shapes have the same value for the same attribute, we say that a *repetition* occurred. Thus, variation and repetition are two opposite but interconnected entities. In fact, they are different ways of looking at the same aspect of the arrangement of elements, and so we refer to this aspect as *variation-repetition.* Variation[4] emphasizes difference, whereas repetition emphasizes equality. In other words, variation describes an arrangement from the diversity viewpoint, whereas repetition describes it from the orderliness viewpoint.

Degree of repetition

We proposed above a method of systematizing the analysis of a given set of elements in terms of diversity and order. Nevertheless, in order for our analysis to be complete we should also be able to quantify order-diversity. Given the relationship between order-diversity and repetitio-variety demontrated above, if we find a way of measuring repetition-variety, we will be able to measure diversity and order. With this purpose, I define degree of repetition. One could also consider defining degree of variation. In fact, one is the inverse of the other. Nevertheless, I will consider degree of repetition, to emphasize that repetition is an element of diversity, as concluded in Section 7.2.18.

Following the distinction between attribute variation and sequence variation, we have to define two different degrees of repetition. The definitions are as follows.

Degree of attribute repetition

Degree of repetition of an attribute *a* of a given shape *s* (in short the *degree of attribute repetition*) is the ratio between the total number of repeated values of an attribute *a* and the total number of shapes *s* existing in the design. The number of repeated values is found by subtracting the total number of

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[4]In our framework, the term variation signifies the quality of changing. It has, therefore, a different meaning from variety, which we would use to refer to *something differing from others of the same general kind (Webster's dictionary)*

different values for attribute *a* from the total number of shapes *s*. We then have the formula:

$$dr_a = \frac{\text{Total number of shapes s - Total number of different values a}}{\text{Total number of shapes s}}$$

dr_a - degree of attribute *a* repetition

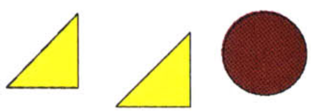


Fig. 7.94
Top horizontal sequence of the arrangement shown in Fig. 7.92

For instance, the degree of color repetition of the top horizontal sequences of the set of elements in Fig. 7.94, is 3 - 2 / 3 = 0.3(3). Note that we took into account the *length* of the sequence by using our definition of degree of attribute repetition. Consider, for instance, the following sequence of five elements:

Fig. 7.95
Sequence of five elements

Relative degree of attribute repetition

This sequence has the exact same number of color repetitions of the previous sequence. However, if we calculate the degree of color repetition, 5 - 4 / 5 = 0.20, it is has a lower value. It expresses, therefore, the fact that it is not as repetitive to repeat twice a color in a sequence of five elements as it is in a sequence of three. In fact, the maximum degree of color repetition we could have for a sequence of three (Fig. 7.95), is 3 - 1 / 3 = 0.66, whereas for a sequence of five is 5 - 1 / 5 = 0.8. As the length of the sequence increases, the maximum degree of repetition increases, tending towards 1.

Thus, the degree of repetition takes into account the factor of scale, so important in the perception of the diversity, as shown in Section 7.2.16. Consider, for instance, that we are measuring the repetition of a certain wall color in a row of houses;

having two houses with the same color in a row of 3, is not as repetitive as having the same number of houses with the same color in a row of five. Thus, I would modify the degree of repetition defined above to *relative degree of attribute repetition.*

Absolute degree of attribute repetition

By comparing the relative degree of repetition to the maximum degree of repetition for the sequence, we can then define *absolute degree of attribute repetition.* This degree of repetition is obtained by dividing the relative degree by the maximum degree. For instance, for the sequence in Fig. 7.96, it would be 0.33 / 0.66 = 0.50, and for the sequence in Fig. xx, it would be 0.20 / 0.80 = 0.25.

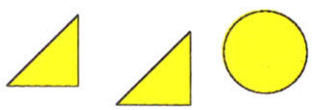


Fig. 7.96
A sequence of three elements with the same color

Once we find all the degrees of attribute repetition of all the horizontal sequences, we can calculate the average degree of horizontal repetition, and then proceed in the same way for the vertical sequences. We can then calculte the *average degree of attribute repetition.*

Degree of sequence repetition

In order to measure sequence repetition, we can define *degree of sequence repetition*, in a similar way to the degree of attribute repetition. Thus, the degree of repetition of sequences (in short, the degree of sequence repetition) in a design, is the ratio between the total number of repeated sequences, and the total number of sequences. The total number of repeated sequences is found by subtracting the total number of different sequences from the total number of sequences. The formula for the degree of sequence repetition is then:

$$dr_S = \frac{\text{Total of number sequences - Total number of different sequences}}{\text{Total number of sequences}}$$

dr_S - degree of sequence repetition

Average degree of repetition

For instance, the degree of sequence repetition in the set of elements in Fig. xx (considering only color and shape) is 6 - 3 / 6 = 0.50. This degree of repetition is *relative*, but we can also define *absolute* degree of sequence repetition. For this given set it would be o.50 / ((6 - 1) / 6) = 0.60. Once, we determine the degree of sequence repetition for the horizontal sequences, we can determine the one for the vertical ones. We can then obtain the average degree of sequence repetition. By calculating the average between the degree of sequence repetition and the degree of attribute repetition, we finally obtain the *average degree of repetition* (in short, degree of repetition) for the given set of elements.

In summary, we have presented above the concepts of value, attribute, and sequence, considering both vertical and horizontal sequences, as a method of analyzing and describing a set of elements. We have based this method on the way the subjects of Experiment A, especially Ana, designed and evaluated their designs, and we have also argued that the method is suitable for describing a housing street facade.

Then, we defined variation, and repetition, concluding that they are two different ways of describing the same feature of an arrangement of elements, called variation-repetition. As a result, we demonstrated that variation is to repetition as diversity is to orderliness, thus confirming the proposition that diversity and order are not opposite concepts but different aspects of the same entity.

Finally, we defined attribute and sequence repetition, and we also defined degree of repetition as a way of measuring repetition-variation. We can, thus, characterize a design in terms of diversity and orderliness.

b) Using the degree of repetition to control orderliness-diversity in a design

It is possible to use the degree of repetition, or the various degrees of repetition, to control the order-diversity of a design such as a housing street facade. Moreover, they can be used as evaluative rules to control the order-diversity of a design generated by a computer program such as the Street Facade Generator proposed at the end of this study.

We have, nevertheless, to find the right balance between repetition and variation, in order for a composition to be perceived as diverse and ordered at the same time. One could be led to think that the perfect balance between orderliness and variety is achieved when the degrees of repetition and variation are the same or, when repetition is equal to variation, which is achieved when the degree of repetition equals 0.5. However, nothing guarantees such a thing. First, such a balance is likely to depend on the person, the group, or the culture: the degree of repetition might have a different value for each of them. Second, each person, group or culture might consider a range of degrees of repetition as acceptable, and so the balance between repetition and variation might take, in fact, the form of an interval, such as [0.4, 0.5].

However, the limits of such intervals are not random. The bottom interval indicates the limit below which a certain artifact might be perceived as chaotic, and the upper limit indicates the limit above which the artifact might be perceived as monotous. Although an accurate definition of these limits requires new experiments, we can, nevertheless, select one of the designs of the present experiments, and calculate its degree of repetition, in order to have an idea of what the balance could be. Then, we can use the value obtained in the development of the Street Facade Generator presented at the end of this thesis as a rule for diversity-orderliness. I selected Ana's design for the reasons that I have already fully explained. Since her design will serve as a basis for the development of our computer program, the use of the degree of repetition of her design is more appropriate. We will calculate the degree of repetition in Ana's design, after we discuss some problems raised by the application of the proposed method to architectural drawings.

c) Application of the proposed method of measuring repetition- to a street facade

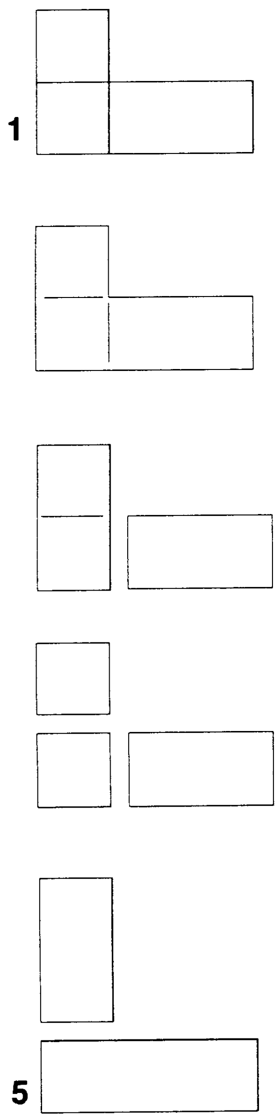


Fig. 7.97
Gestalten theory: the same generic form (1) can be interpreted in multiple ways, but the simplest one is more readily apprehended (5)

As we mentioned above the proposed method of measuring repetition-variation is appropriate for a street facade. However, we have to overcome some additional problems related to element recognition. Element recognition or shape recognition, in the usual terminology, has been addressed by Gestalten theorists as well as by shape grammarians. Element recognition is important in the measurement of repetition because it determines which elements and sequences should be considered. The perception and recognition of shapes is not as straightforward as one could think. In fact, the same arrangement of elements can produce multiple interpretations of form (Fig. 7.97), even though Gestalten Theory states that the simplest one is more readily apprehended. Additionally, the functional meaning of shapes also influences the recognition of elements, as pointed out in Section 7.2.11. In the set of elements we used in the description above (Fig. 7.92) there were no such element recognition problems since the elements were clearly defined and abstract.

Nevertheless, such problems were overcome in Ana's design. In fact, in her design the shapes are clearly identifiable, unlike in some of the other designs. Moreover, in her design there is a high degree of identity between form and function, as shown in Section 7.2.15. Thus, the analysis of Ana's design process diagrammed in Fig. 7.42 can easily provide some guidelines for the definition of elements and sequences. In fact, the diagram clearly shows that she performed specific design operations in order to complete her design. It also shows that

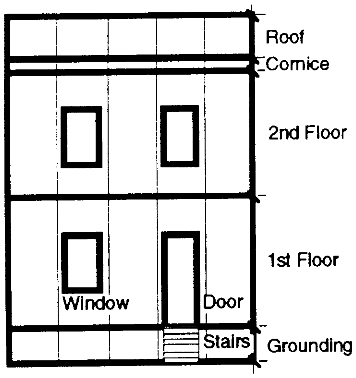


Fig. 7.98
Functional-formal elements of Ana's design

each operation corresponded to a specific formal and functional element that she mentioned in her Verbal Protocol. Therefore, we can define the elements and the sequences of her design following the operations she performed. These elements are: house, grounding, wall, door, window, cornice and roof, and are illustrated in Fig. 7.98.

The universe of elements, attributes and values of Ana's design is diagrammed in Fig 7.99, and shown in Table B.XIV. Note that we include in her universe of values not only the values she used, but also values she could have used without disregarding the essential rules of her design. We will consider these extra values for the universe of values to be used by the computer program presented at the end of this study, with the goal of enlarging the possibility of generating diverse designs, as we will later discuss. Nevertheless, we distinguish her values from the other values either by using a thicker line for her values in the diagrams, or by using italics for the other values in Table B.XIV.

The list of values for each attribute taken by specific elements in her design are shown in Table B.XV. It will serve as a basis for the calculuIation of the degrees of attribute and sequence repetition for the horizontal sequences in her design. The calculuIation of the same degrees of repetition for the vertical sequences require some additional considerations related to the functional meaning of elements. In fact, if for the horizontal sequences, we can compare the repetition of each attribute from house to house, for the vertical sequences we cannot do the same thing. We have to guarantee that we are comparing elements and attributes with the same function. For instance, we have to compare a floor to a floor, or windows to windows. Nevertheless, the comparison of elements with different functions can also be architecturally meaningful for some attributes, if the elements belong to the same fuctional

Bold lines:
values used by Ana

Thin lines:
values she could have used

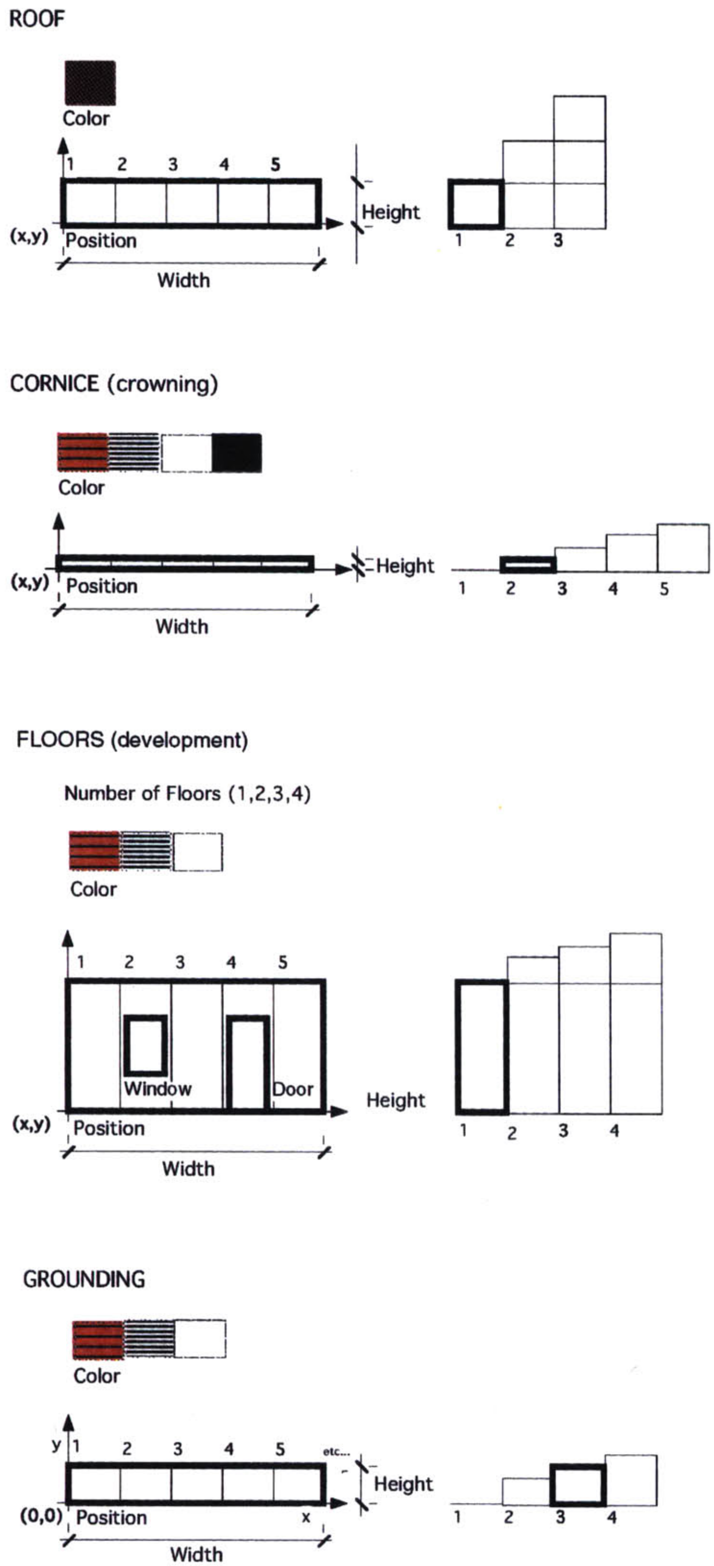


Fig. 7.99
List of Attributes and Values of Ana's design

DOORS AND WINDOWS

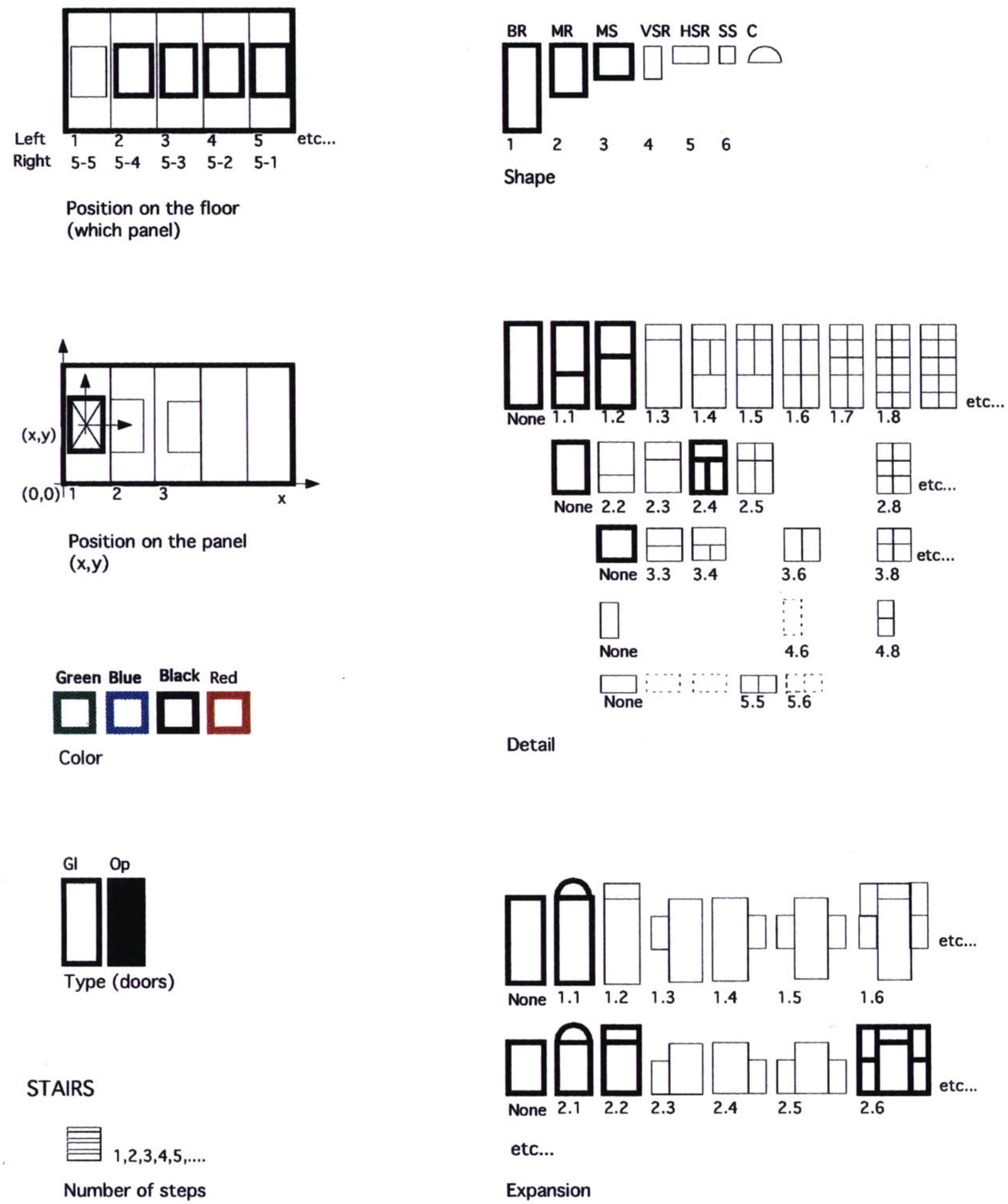


Fig. 7.99
List of Attributes and Values of Ana's design

scale, such as the widths of the grounding, the floors, the cornice, and the roof, or if the attribute is color. In fact, color is the only attribute that can be compared disregarding scale and function. The underlying hierarchical scale of the elements in Ana's design is, from top down:

house

grounding, floors, cornice, roof

window, door, stairs

The hierarchy continues throughout the details of the windows and doors. However, the forms that compose those details, which are of two types, internal details and expansion details, are more like attributes of the doors and the windows, than independent forms themselves, and so they were considered as attributes of these elements. Thus, we divided the elements in Ana's design design into two categories: *superstructure*, including the grounding, the floors, the cornice, and the roof; and *openings*, including the doors and the windows. Using these categories for both the horizontal and the vertical sequences and for all the attributes, we calculated the degrees of repetition in her design.

d) Degrees of repetition in Ana's final design

In order to calculate the degree of repetition in Ana's design, we first calculated the degrees of attribute and sequence repetition for the horizontal sequences, and then the one for the vertical sequences. The results are summarized in Table V, and briefly discussed below.

Table V
Average Degrees of Sequence and Attribute Repetition in Ana's Design

	Superstr.			Openings			Total		
	H.	V	Tot	H	V	Tot	H	V	Tot
Dr_a	0.65	0.44	0.55	0.55	0.06	0.31	0.60	0.25	0.43
Dr_s	0.76	0.80	0.78	0.25	0.97	0.61	0.51	0.89	0.70
Dr	0.71	0.62	0.67	0.40	0.52	0.46	0.56	0.57	0.57

d.1) degree of attribute repetition

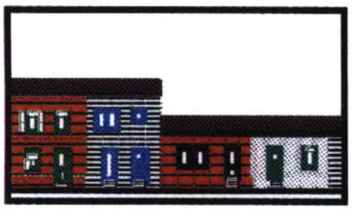


Fig. 7.100
Ana's design

The degrees of attribute repetition for the horizontal sequences in Ana's design are shown in detail in Table B.XVI Appendix B.6). The average degree of attribute repetition for the horizontal sequences in the design is 0.60. The degrees of attribute repetition for the vertical sequences are shown in detail in Table B.XVII. The average degree of attribute repetition for the vertical sequences in the design is 0.25. The difference between the two values is a result of the existence of a horizontal functional parallelism between the elements, a house on the side of a house, a grounding on the side of a grounding, which causes a certain harmonization of attributes between elements in horizontal sequence. The lower values for the vertical sequences is a result of the lack of such functional parallelism between the elements in vertical sequence: grounding - floor, cornice - roof, and door - window. The lower value is also a result of the few number of floors of each house (one or two), which diminishes the possibility of functional repetition. The degree of repetition is especially low for the openings (0.06), and is a result not only of the function, but also of the change in the value of the attributes such as details and expansion, from the ground to the first floor. This low value, shows the important role of the existence of diverse openings in the perception of diversity in Ana's design.

Ana's average degree of attribute repetition for the horizontal sequences is 0.43.

b.1.2) Degree of sequence repetition

The degrees of sequence repetition are shown in detail in Table B.XVIII. The degree of sequence repetition in Ana's design for the horizontal sequences is 0.51. The degree of sequence variation for the vertical sequences is 0.89. The differences in these values and their comparison with the degrees of attribute repetition, show that in order to balance the low degree of attribute repetition of the horizontal sequences Ana made the attributes sequentially vary in many different ways. And in order to balance the high degree of attribute repetition of the vertical sequences, she constrained their degree of sequence repetition. She did so in such a way that the average degree of repetition for both the horizontal and vertical sequences sequences are almost identical: respectively, 0.56 and 0.57.

The average degree of sequence repetition is 0.70, considerably higher than, her average degree of attribute repetition. I argue that by using a high degree of sequence repetition, Ana guaranteed that her design achieved a high enough degree of orderliness in order to be perceived as ordered. In fact, her houses are variations of the same prototype, as we pointed out in Section 7.2.11, having a sense of familiarity given by a sequential repetition of elements, such as grounding - flooors - cornice - roof, carried out from house to house. On the other hand, I argue that by using a high degree of attribute repetition, Ana guaranteed the satisfaction of the diversity requirement without compromising the order of her design. I also argue that this strategy enabled her to create a diverse design based on few elements.

b.1.3) average degree of repetition of Ana's final design

The average degree of repetition in her design is 0.57, a value that is practically identical to the average degrees of repetition for the vertical (0.57) and horizontal sequences (0.56). It suggests that for Ana, the balance between orderliness and diversity was somewhere around 0.57. This value is also close to 0.50, the value one should expect balance to be.

In conclusion, the concept proposed, that of degree of repetition, help us to understand the strategy used by Ana to achieve order and diversity in her design. The degree of repetition can thus be used in a reverse way, to control orderliness in a design. Moreover, since it is a mathematical concept it allows its use by a computer program such as the Street Facade Generator.

7.2.18.2 Logic order

How is order perceived?

1.2

Logic order: generative and evaluative logic

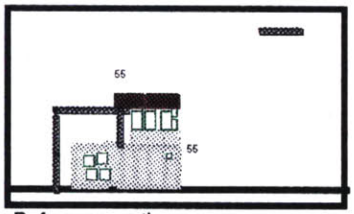
Designers (and non-designers) needed to logically explain the decisions they made in their generation of forms

Designers (and non-designers) needed to perceive logic behind the forms whose generation they did not control

Logic promotes orderliness

Logic order is the result of our need to tie the development of the design to some logical generative rule. In other words, it is related to what I have explained in Section 7.2.11 as our need for logic. Since this need was fully explained in that section I will just review very briefly how and why it evolves, and then I will try to explain how it contributes to the perception of order. As said in the section mentioned above, the need for logic is connected to our need to freeze variables which in turn is connected to our short-term memory limitations. The use of a sequential logic rule, developed as the design process evolves, facilitates the decision making process for the designer. Since decisions are made on the basis of if...then, the need for logic is, undoubtedly, a reflex of a rational mind. However, I think that this rationalism is not solely a need for those who are designing because they need to make decisions. I think that it represents something deeper. How could we then explain comments like the one Ana made to justify the increasing placement level of her doors due to her inability to place them accurately with the mouse? She said:

The doors are climbing... Well, the street can be sloppy.



Before correction

Fig. 7.101
Salvatore's design

These type of comments were frequent. For instance Salvatore justified the misplacements of his windows by saying:

> *It doesn't matter. Let's say it is bad carpentry.*

Therefore, it seems that not only do people need to logically explain the forms they create, but also to perceive logic behind the forms whose generation they did not control. In this sense, this need is part of their effort to understand these forms. I have no doubts that these two forms of need for logic are connected to each other, and that them are both important in architecture; if one is connected to the generation of form by designers, the other is present in those who use and criticize the work of the first, and therefore they are both fundamental to any of us. To acknowledge this is very important if we are concerned with the generation of diverse environments that are pleasantly experienced by people.

On the other hand, as we also have already explained in Section 7.2.11, the need for this type of order restricts designers' ability to generate diverse designs, since they will not make variations of any form if they do not find reasons for it. Unfortunately, the level of abstraction at which designers need to work, due to their immediate memory constraints, prevents them from keeping track of smaller design requirements that could explain the generation of such variations. As an example of this process recall, for instance, the rule that Wade developed (Section 7.2.12) to control the placement of his panels. Note that his rule was not totally incompatible with the idea of diversity, because he did use all the panels available. However, as we saw, the clear division of his design into fields that resulted from that rule led Taylor to consider Wade's design as not that diverse. Therefore, if Wade's need for order was not incompatible with the use of diverse elements, it did prevent him from achieving a higher degree of diversity and caused him to generate a more orderly design. Logic order promotes, thus, orderliness.

In conclusion, the experiments suggested the existence of two types of logic; one linked to the process of generation of designs by their authors, and another linked to the process of evaluation of those designs, either by their authors, during the design process, or by someone else. Each of these types of logic has a different role: the first constrains the generation of diversity by designers, promoting orderliness, and the other constitutes a requirement for the perception of an architectural artifact as ordered by people in general.

7.2.19.3 Balance

How is order perceived?

1.3

Balance: vertical and horizontal balance

Designers (and non-designers) needed to balance their designs

Balance is a form of ordering a diverse design

In the discussion of the results of "The Spoken Game with Abstract Elements" we showed that when asked to generate diversity, the subjects exhibited a trend towards order, seen as balance, and we mentioned the existence of horizontal and vertical balance. Additionally, we mentioned that the perception of horizontal balance was related to the value of the areas above and below an horizontal axis taken as reference in the composition. Two mathematical models were proposed for the perception of each of these types of balance. Considering that in the experiment with abstract elements, designers were free to approach the problem in a compositional fashion, one can certainly argue that balance might not be a concern in the design of a facade, or that the mathematical models then proposed might not be accurate in this case. However, the results of the "Spoken Game with Architectural Elements" showed that when asked to generate diverse designs, the subjects, be they designers or non-designers, were also concerned with order seen as balance. Moreover, the mathematical models proposed are applicable, when drawings with architectural meaning are concerned, if some considerations are taken into account and introduced into the models.

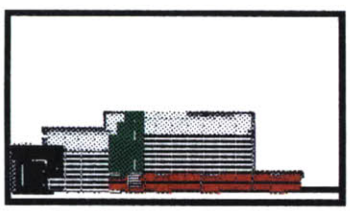
As a matter of convenience, the following discussion is divided into two parts: the first is concerned with vertical balance, the second with horizontal balance.

Vertical Balance

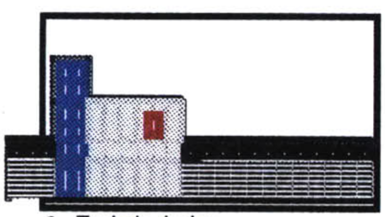
The model developed for vertical balance on the results of the experiment with abstract elements can be applied to facades

The following discussion involves two steps: the first explores the validity and the constraints of the mathematical model proposed for vertical balance, and the second tries to show how strong was the subjects' concern for balance. The reason for this apparently illogical inversion is quite simple: in our pursuit to see to what extent the subjects were concerned with balance we faced some difficulties. Namely, if the concern for balance was evident and easy to explain in almost all the designs due to obvious symmetries, it was not so easy in Wade's and Taylor's designs. In Wade's design, we failed to see how his design was balanced. We could certainly accept that Wade's failed to balance his composition. However, even considering that it did not have to be in balance, we should anyway be able to explain why it was not in balance, and why Wade failed to achieve it. In Taylor's design the problem was quite different. His design seemed to be strongly balanced, but since the facade was not symmetrical, that balance was difficult to explain. Additionally, we thought that since Taylor was replying to Wade's design and since his design was balanced, whereas Wade's was not, we could make the argument that if Wade failed to achieve balance, Taylor tried to correct his flaw. However, that required us to use a model that could simultaneously explain Wade's failure and Taylor's success. If the previous model proved to be successful in achieving this goal, we would not only test the model's ability to explain a difficult situation, but also reinforce our argument that the subjects have a trend towards balance.

Fig. 7.102
Wade's design



1 - Wade's design



2 - Taylor's design

Fig.103
Taylor's design

In order to accomplish our goal we will proceed as follows. First, we will analyze Wade's design and show how he was concerned with symmetry and balance, and how we can also consider his design as informed by reference axes. Second, we will explain the differences between compositional balance and balance in the design of a facade. Third, we will explain the sources of these differences, and address the implications and problems caused by such differences. Finally, we will propose a way to take these differences into account and introduce them into the mathematical model proposed on the results of the "Spoken Game with abstract Elements." After this discussion, we will test the validity of the model using Wade's and Taylor's designs. Only then will we show how the other subjects were also concerned with vertical balance.

Towards a mathematical model for vertical balance in the design facades

Recall Wade's design process analysis diagrammed in Fig. B.10. As we have mentioned earlier, balance can be achieved through symmetry. If symmetry is not apparent in Wade's final design, it is nevertheless present in his conceptual idea (Fig. 7.103): a central doorway with clear-story spaces on both sides, and a porch on each extreme. As we saw in Section 7.2.11, the first part of Wade's design process—when he was concerned with building his structure—was characterized by a constant struggle between the need to achieve diversity and the symmetrical character of his conceptual idea. The need for symmetry was so important that when he built his fifth bay he saw it as space within a space, rather then as an independent space itself, allowing thus, the survival of his symmetrical conceptual idea (Fig.103-2). We also saw that he later tried to hide the diversity he had achieved for his structure, when he applied the wall panels. In fact, the placement of the panels mirrored the symmetrical conceptual idea of the design: green glazing for the central doorway, white brick for the clear-stories and whitewash for the upper floors space. In conclusion, symmetry is a fact in Wade's design, and therefore, so is balance.

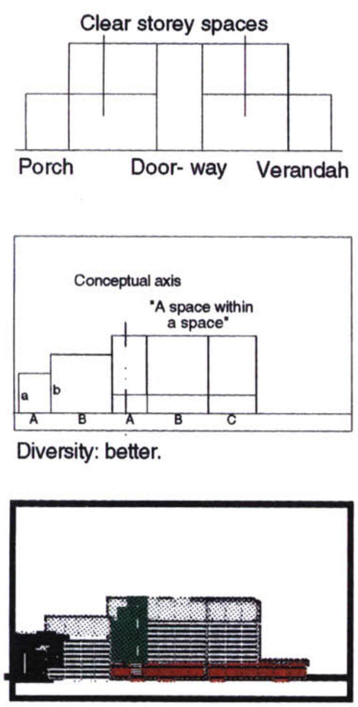


Fig. 7.103
Although symmetry is not apparent in Wade's final design (3), it was in his conceptual idea (1), and during his design process (2)

Accepting that balance was present in Wade's design process, we should consider if it was informed by reference axes in a similar way to that followed by Thomas in the "Spoken Game with abstract elements." If it was so, the use of these axes could open way to the application of the abstract mathematical model to Wade's facade. The various reference axes of Wade's design are illustrated in Fig. 7.105. There are some differences between Thomas' and Wade's design processes. Recall that for Thomas, the axis of the drawing board, and the axis of the designed area were his reference axes, and that his compositional axis, calculated according to the formula proposed, was between the two. The position of that axis mirrored the conflict between the different positions of the axes that Thomas' selected as reference (Section 7.1.10). Behind the impossibility of having an unique axis, the ambiguous position of the compositional axis, satisfied the designer in such a way that although it was not none, it could be both. This ambiguity was only possible because the two reference axes were incidentally very close to each other, and because Thomas designed the composition in such a way as to have the compositional axis between those two reference axes. In Wade's design things are more complex because there are more axes that can be taken as reference, because there is a bigger discrepancy between the reference axes, and finally, because it is more difficult to determine how the compositional axis should be calculated.

The source of the difficulties of Wade's design is threefold. First, his design has an architectural meaning, and consequently, there are other axes that constitute important references such as the entrance axis (Fig. 7.105-2,2a). Second, because Wade had to design a facade his design is not made of disperse elements like Thomas' abstract composition. In these circumstances arises the doubt of which axis should be taken as the axis of the designed area: the axis whose x coordinate was the midpoint between the extremes of the design (Fig. 7.105-4,

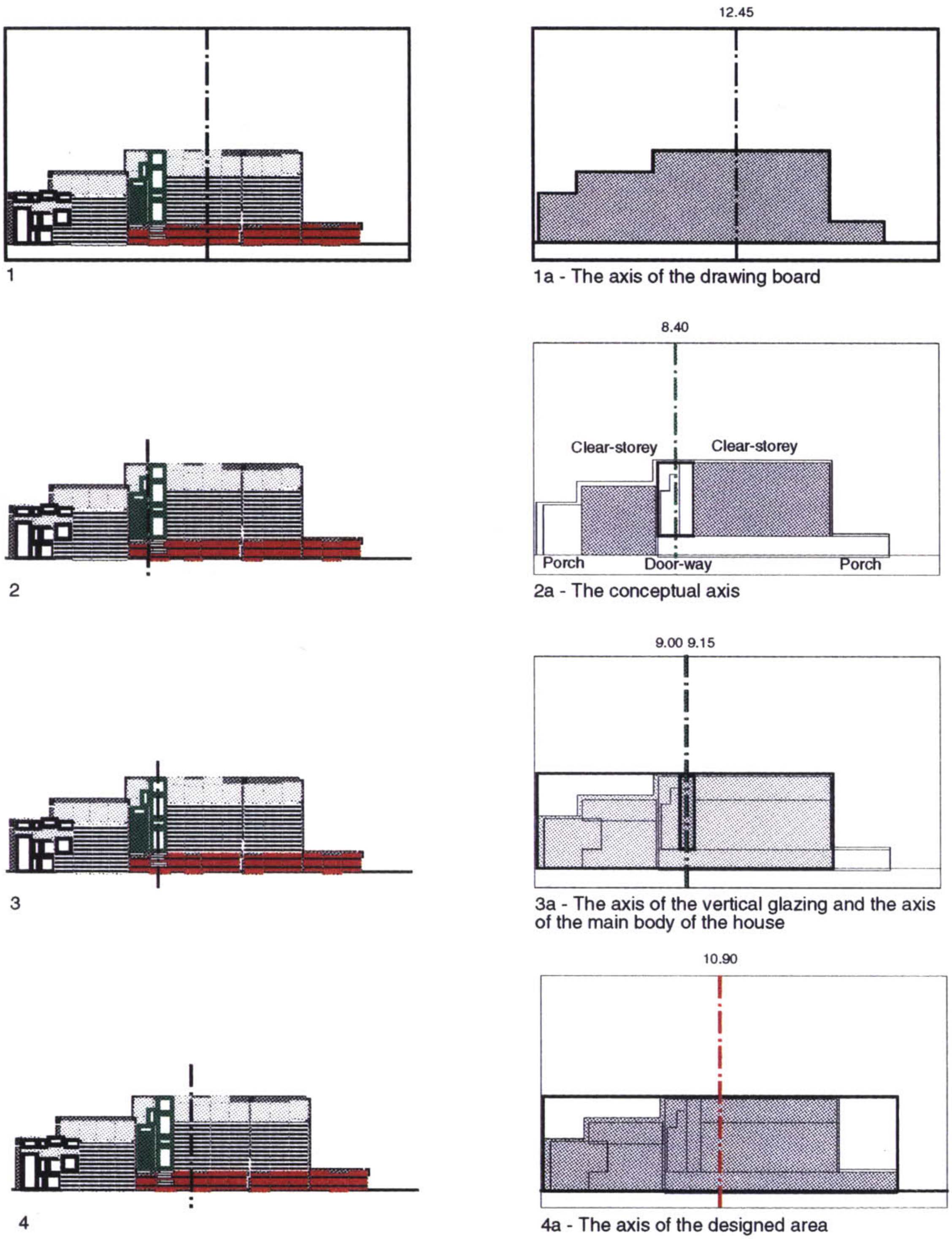
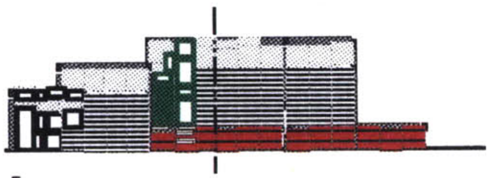


Fig. 7.105
Reference Axes of Wade's design process



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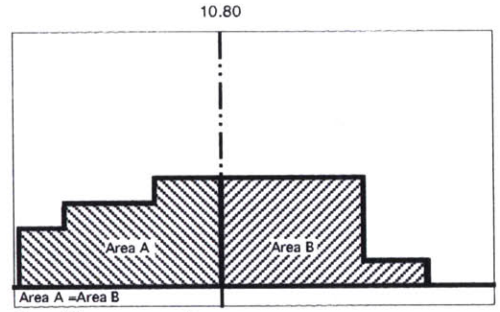
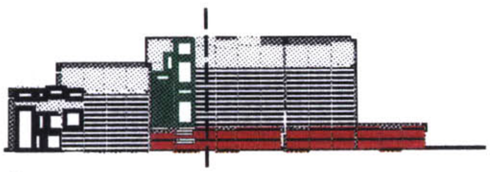


5a - The area axis



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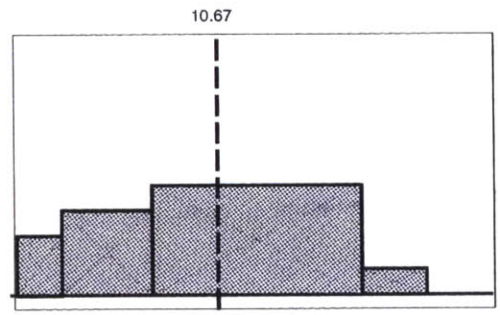

6a - The compositional axis assuming that different colors have the same visual weight

Fig. 7.105 (continued)
Reference Axes of wade's design

4a)—like Thomas did, or the axis that divided the design in two halves of equal area (Fig. 7.105-5,5a). Third, because Thomas' design was an abstract composition, almost a painting, the drawing board was itself part of the design, and therefore, it was not difficult to consider its axis as a reference axis. However, in Wade's it is not so easy to make that assumption, since the design was supposed to be the facade and not the facade plus the drawing board. Even considering that the presence of the drawing board was important in Wade's design process, it is still difficult to determine how important it was, and how influential the axis of the drawing board should, in fact, be as a reference axis (Fig. 7.105-1,1a).

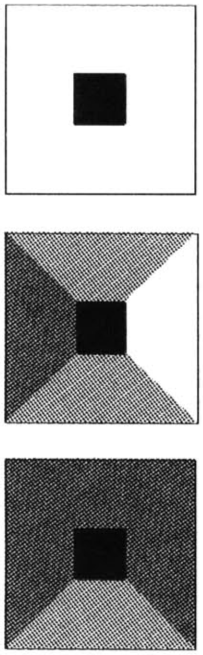

Fig. 7.106
A varied background has influence on a shape's visual weight

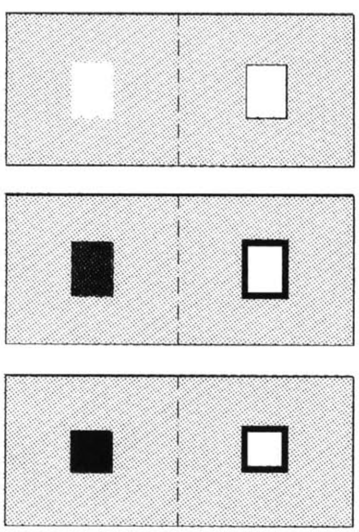

Fig. 7.107
It is difficult to determine the visual weight of shapes like windows

The question of how important is the drawing board in the design of a facade has, obviously, some implications. Recall that in the formula for balance, we considered that the weights of each color should be measured against the background. But what should we consider the background in the case of facades in which shapes were adjacent or overlapping? Moreover, considering the design of the facade as the actual design goal, should we judge it in terms of balance against a background, that might even vary from reality? It seems that the balance of a facade should be independent of its background. This assumption leaves us with two problems. First, the problem of how to determine the compositional axis when the drawing board is irrelevant, and second check how each of the two cases corresponds to Wade's design.

To solve the first problem, we have to address two issues. First, we have to find a way to measure the visual weight of shapes that are adjacent to other shapes. In other words, we have to define a background. Second, we also have to find a way to measure the visual weight of shapes like windows, composed of overlapping shapes. This issue obviously is a particular case of the first one. The influence of a varied background on the perception of the visual weight of a given shape is illustrated in Fig. xx, whereas the difficulty of how to measure the visual weight of shapes like windows is illustrated in Fig. xx. By looking at these figures, we can acknowledge that the visual weight of a shape is influenced by the area, proximity, and colors of adjacent shapes, but we can also confirm the difficulty of measuring such influence. One way to go to solve our problem would be to vary the area, proximity, and color of background shapes and then measure experimentally the visual weight of our shape by matching it against successive shapes in standard conditions (uniform shape on a uniform background) until a shape of equivalent weight was found. However, I want to propose an alternative and easier solution. Recall the Yin and Yang symbol.

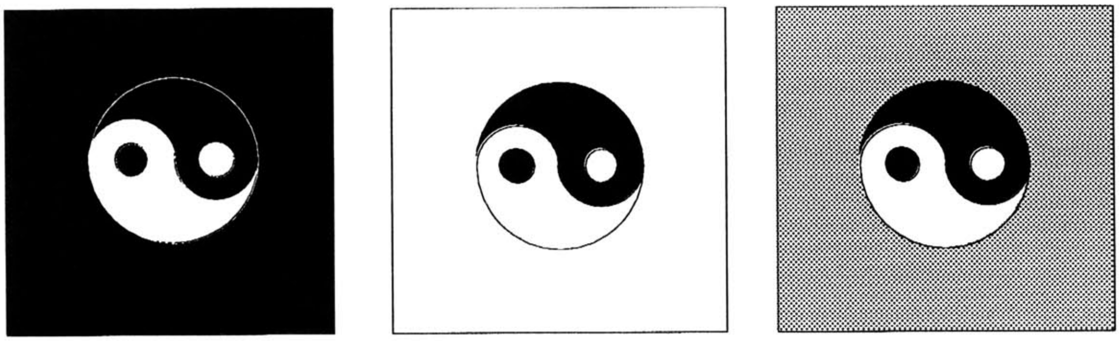

Fig. 7.108
The yin and yang symbol

The symbol does not look in balance when placed against a white background, for instance. However, something tells us that it is a balanced composition. In order to prove that, we place it against a gray background. Not any gray, but a gray that results from the exact mixture of equal amounts of white and black. In other words, that gray has a visual weight that is the average of the visual weight of the colors in the composition measured against a white background. Therefore, we find a way to measure balance in a composition whose shapes are simultaneously foreground and background. The visual weight index of shapes in those circumstances is then given by the formula:

$$w_{nav} = wn \; \frac{w_1 A_1 + w_2 A_2 + \dots + w_n A_n}{A_1 + A_2 + \dots + A_n}$$

(5) average visual weight index[5] formula

w_{nav} - visual weight index of shape n against a background whose visual weight is the average of all the visual weights of all the colors in the design

w_n - visual weight index of shape n against a white background

A_n - Area of shape n

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[5] In order to simplify the language, from now on we will use the abreviated term *average visual weight* to designate the average of the visual weights of the shapes in a composition and *average background* to refer to a (virtual) background whose visual weight is the average visual weight

This formula measures the influence of the area and the color of the various shapes in the background in the perception of the visual weight of a given shape. It also makes it possible to calculate the visual weight indexes of shapes like windows, using both the visual weight index of the frame and the visual weight index of the glazed area. It does not measure, however, the influence of the distance of each shape taken as background to the shape whose visual weight we want to measure. In order to do that, we have to take into account the value of that parameter in the calculation of the visual weight. It is not hard to see that the influence of a shape in the perception of another's visual weight diminishes as the distance between them increases. Thus, a plausible way to consider the influence of distance between shapes on the calculus of the visual weight index of a certain shape would be to multiply the product visual weight $w_n A_n$ of each shape taken as background, by the inverse of the distance of that shape to the shape whose visual weight we wanted to measure. That formula would then take the following form:

$$w_{nav} = wn — \frac{w_1 A_1 \, 1/d_1 + w_2 A_2 \, 1/d_2 + \ldots + w_n A_n \, 1/dn}{A_1 + A_2 + \ldots + A_n}$$

(6) average visual weight index formula
(Considering the influence of distance)

d - distance of the center of the background's shape to the center of the shape whose visual weight we want to measure

However, due to the formula's requirement of calculating separately each shape's visual weight index, we will use the simplified formula (5). In fact, that requirement would imply: first, an increased difficulty of confirming experimentally the validity of that formula within the time constraints of this thesis, and second, a greater use of computer memory by a program developed to design balanced compositions after the formula. The error caused by the use of the simplified formula (5) can be

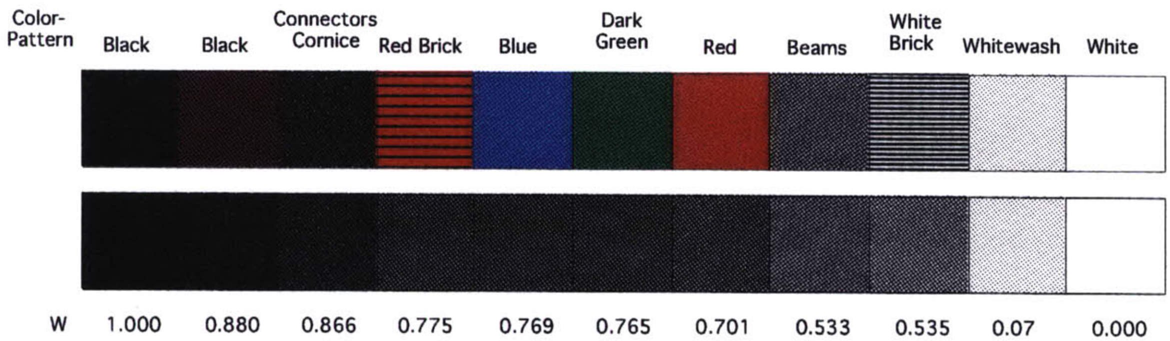


Fig. 7.109
Visual Weight indexes of the color-patterns used in the "Spoken Game with Abstract Elements"

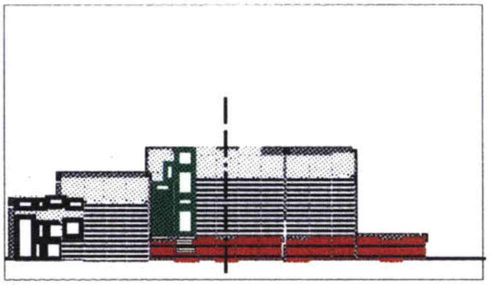
considerably reduced by the use of the following rule: for shapes whose background is clear, such as punched windows in a wall, we will measure the visual weight of that shape against its background, instead of against the average background.

In conclusion, we propose a way to obtain the visual weight indexes of shapes in a composition of adjacent shapes—such as facades—solely on the basis of the shapes in that composition, and taking into consideration each shape's influence on the perception of the visual weight of each of them. We have now to find which of the two models is more accurate in describing the process of designing a facade, and which one better simulates the perception of balance in a facade, and therefore should be used to generate balanced facades.

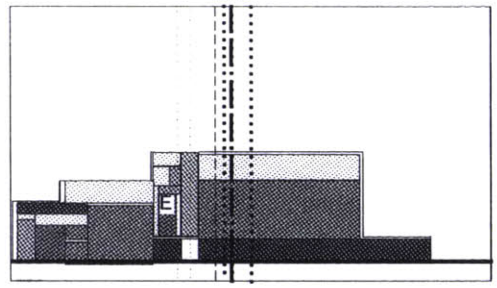
Testing the validity of the model

a) Wade's design process

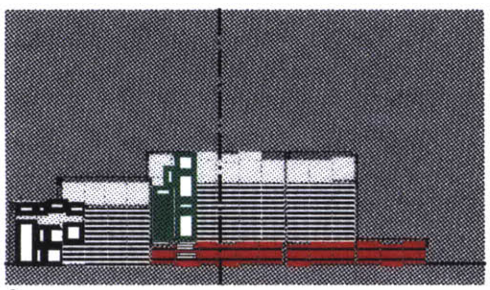
We will first use Wade's design to test the proposed model. In order to accomplish our goal, and according to what was said above, we will calculate the compositional axis of Wade's design against a white background (first model), then against a background whose visual weight is the average visual weight (second model), and then compare our ability to use each of the results in interpreting Wade's final design. Then, according to our conclusion, we will try to describe Wade's design process.



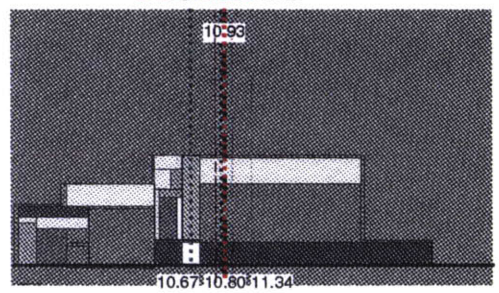
1



1a - The compositional axis assuming that different colors have different visual weights



2



2a - The compositional axis assuming that different colors have different visual weights measured against a background whose visual weight is the average of all the design's colors visual weights

Fig. 7.110
Compositional axes of Wade's design using as references a white background (1), and an average background

The visual weight indexes of the color-patterns used in the "Spoken Game with Architectural Elements" are shown in Table B., and the transformation of those color-patterns into gray-tones according to their visual indexes is illustrated in Fig. 7.109. The calculation of the x coordinate of the compositional axes of Wade's design are presented in Appendix B.4, and the location of such axes in the design are illustrated in Fig. 7.110. The axis whose x coordinate is calculated using visual weight indexes measured against a white background[6] is represented in Fig. 7.110-1 (initial model), and the axis whose x coordinate is calculated using visual index using an average background (second model) is represented on Fig. 7.110-2.

[6] In order to simplify the language in the disussion that follows we will refer to this axis as the *white background axis*, and to the correspondent mathematical model as the white background model. This simplification is not accurate since the model can be, in fact, applied to a composition with a background of any color. However, since the designs under discussion have a white background, the use of such simplification facilitates the reader's task.

Which axis constitutes the vertical balance axis of Wade's facade?

Let's look at Figs. 7.110-7 and 8 and try to judge the design and the facade in terms of balance relatively to each of the axes. If we look at Fig. 7.110-7, and try to concentrate on the facade ignoring the white background, we can see that Wade's facade itself (without the drawing board) does not look in balance relative to the white background axis. It seems that the compositional axis should be slightly to the left. In fact, if we look at Fig 7.110-8, it does look better balanced relative to the axis calculated against an average background. On the other hand, the entire design (facade plus the drawing board) looks in a better balance in the first case (white background axis), whereas it does not look so in the second case (gray background axis). So, we can conclude that the average background axis is more likely the compositional axis of Wade's design than the white background axis, whereas the white background axis is more likely the axis of the entire design (facade plus the drawing board). Therefore, both axes are accurate if we consider that each of them corresponds to a different kind of abstraction.

How do they perform in explaining the design within each of their abstractions?

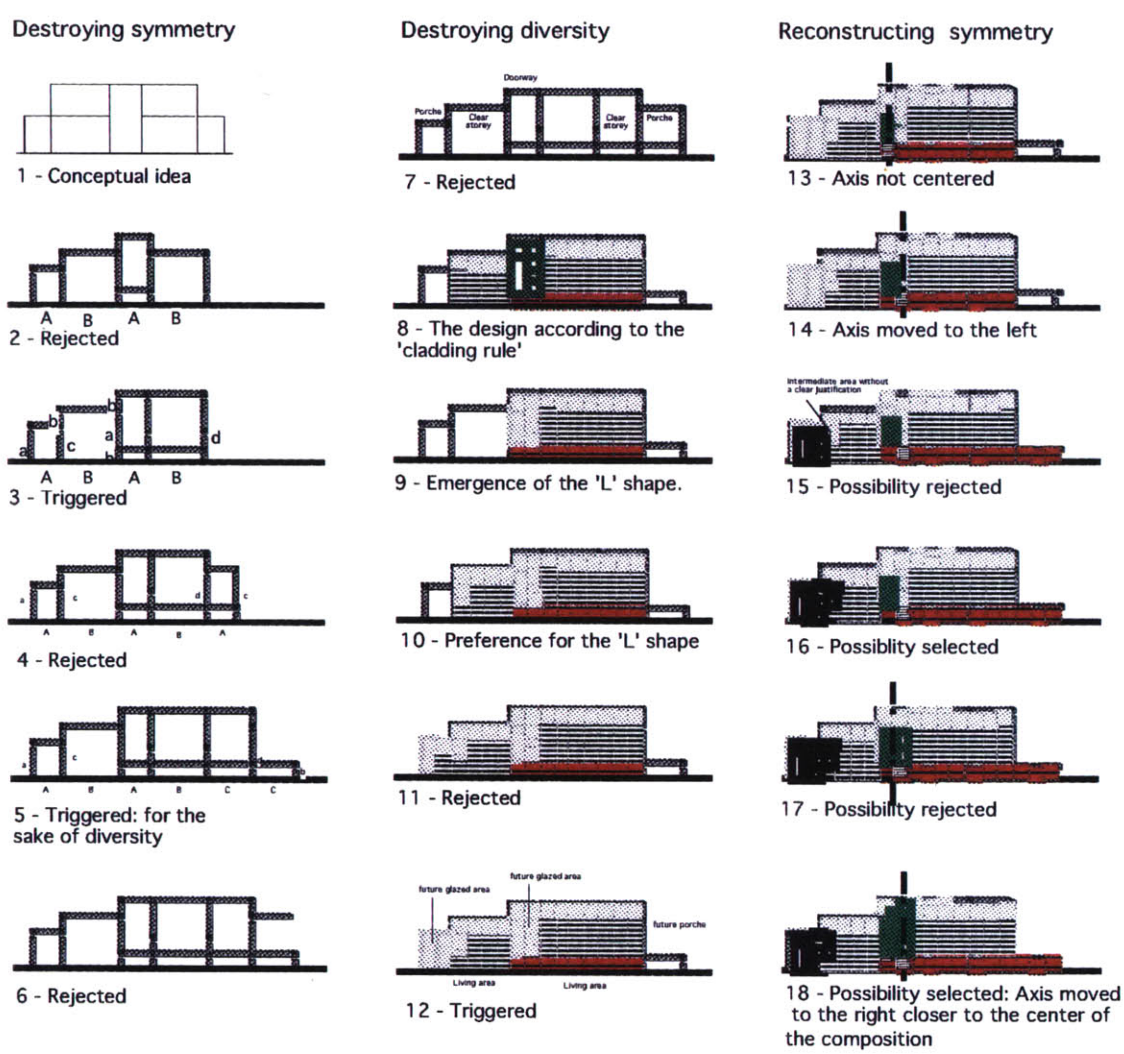
In the abstraction of the white background model we have to consider the facade and the drawing board. The composition looks in a better balance relatively to the white background axis than to average background axis because it is closer to the drawing board than the other. This is explained because in this abstraction, the red grounding looks heavier when measured against the white background than when measured against the colors in the design. Since this abstraction implies a simultaneous concentration on the facade and on the drawing board, our degree on concentration on the details of the facade necessarily has to diminish. Thus, it is more natural to consider as second reference axes those axes that are associated with general features of the design, such as its area or its extremes. Therefore, the mid-area axis or the designed area axis are better candidates for additional reference axis than the vertical glazing axis. So, we can explain why the composition (design plus board) is not in balance in this abstraction: it is not in balance because the white background axis is closer to the designed area axis than to the axis of the drawing board.

In the abstraction of the average background model, the axis of the drawing board does not exist. It has to be substituted by the design area axis, and by the mid area axis. Each of these axes also corresponds to a different abstraction. Considering the general features of the design such as area and extremes, the composition does look in balance. This is explained because the compositional and the reference axes are very close to each other. However, since in this abstraction we are not concerned with the drawing board, we can pay attention to other details of the design. In these circumstances, it is natural to consider the vertical glazing axis as an additional reference axis. Once we value the vertical glazing axis, the design does not look in balance anymore. According to the model, this happens because the average background axis is not between the reference axis but to their right.

We have just seen that if we consider that each model corresponds to a different kind of abstraction and each axis to a different viewpoint, we can build a description of Wade's final design in terms of balance that satisfies our perception. Additionally, if we consider that Wade was indeed concerned with the drawing board (as our previous discussions suggest), and if we show that he took alternatively different viewpoints during the process of designing the facade, we can argue that he was not able to design a balanced facade because he was trying to balance the composition.

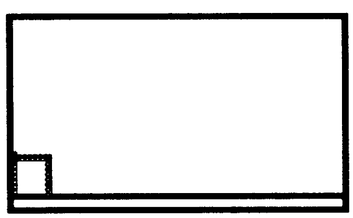
I will show, that in fact, by accepting the existence of different abstractions and viewpoints, one is able to clearly explain Wade's design moves, and so confirm the validity of this framework. This explanation assumes a conflict between two rules, one aiming for diversity, and the other for order seen as balance, and a struggle between several reference axes that inform the perception of balance in a design. Some of these axes have a mere compositional value, whereas others also have an architectural meaning. According to our theory, the facade would be in perfect balance if the all the axes coincided with each other. However, the lack of such coincidence accounts for the story of Wade's design process, explained below, summarized in Fig. 7.111, and detailed, as mentioned, in Fig. B.10.

Fig. 7.111
Summary of Wade's design process

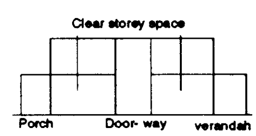


Wade's design process can be divided into three parts (Fig. 7.111): first, he was concerned with building a diverse structure, destroying the symmetry of his conceptual idea; second, perceiving the diversity he had achieved as too much, he cared about destroying that diversity through the placement of the wall panels; and third, he was simultaneously concerned with reconstructing the symmetry of the design, and achieving more diversity, through the placement of the doors and the windows.

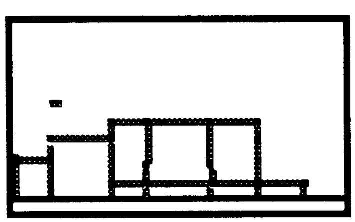
The tension in Wade's design process originated when Wade started his design on the left side (Fig. 7.112-1), since that would oblige him to extend his design to the right side until the axis of the design coincided with axis of the drawing board. However, he constrained the possibility of balancing the composition by defining a conceptual axis too much to the left. We can then understand the need to build a fifth structural bay (Fig. 7.112-2). By building that bay, not only was he satisfying the requirement for diversity, but also moving the axis of the design further to the left, close the axis of the drawing board. After he built that structural bay, Wade moved on to built the right porch. Building a covered porch would have moved the axis of the design closer to the axis of the drawing board. However, he was prevented from doing that in order to satisfy the need for



1- After six moves



Schme of Wade's conceptual idea



2 - After fifty five moves

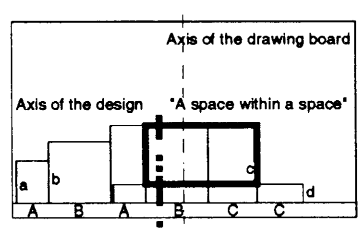
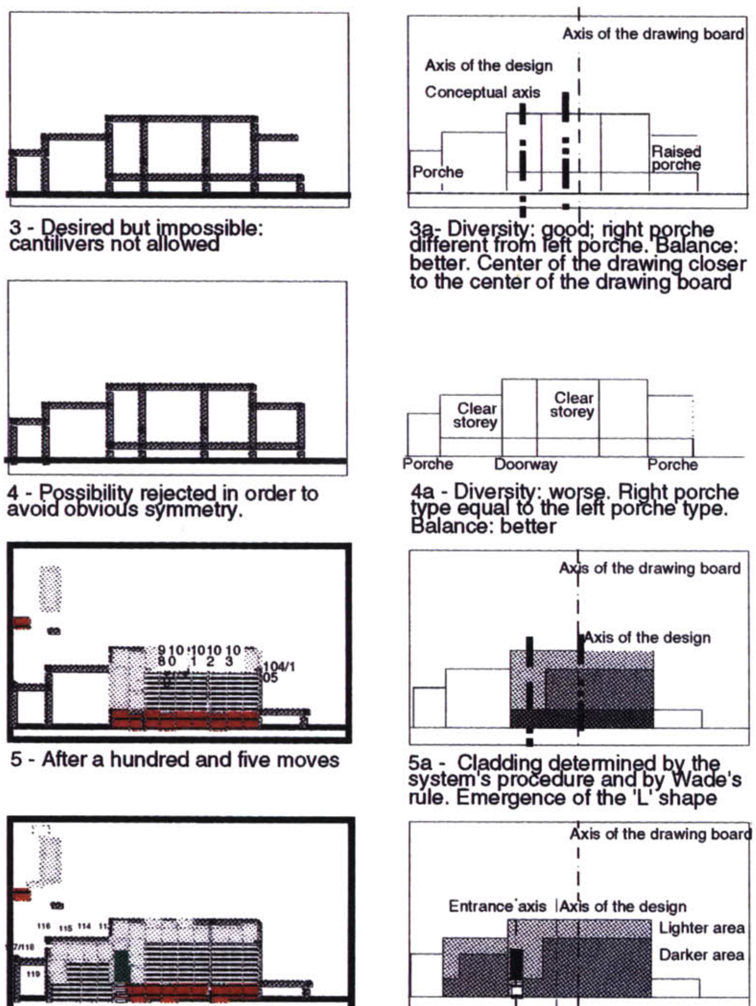


Fig. 112
Wade's design process analysis

diversity (Fig. 7.112-3,4). After Wade defined his panel placement rule, he clad the central area of his design. At that point, the axis of the design became coincident with the axis of the drawing board, and he acknowledged that exclaiming: *very compositional!*

Nevertheless, Wade decided to follow his initial intent (could he explain the existence of two empty spaces on the left, one after the other?), but he was also taken by the compositional qualities of the "L" shape of the first panels that informed the placement of the rest of the panels (Fig. 7.112-5). In the meanwhile, he placed the door, and built the stairs of the central



3 - Desired but impossible: cantilivers not allowed

3a- Diversity: good; right porche different from left porche. Balance: better. Center of the drawing closer to the center of the drawing board

4 - Possibility rejected in order to avoid obvious symmetry.

4a - Diversity: worse. Right porche type equal to the left porche type. Balance: better

5 - After a hundred and five moves

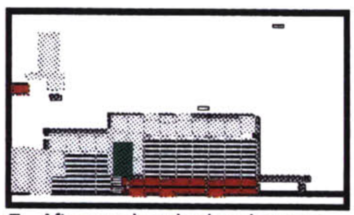
5a - Cladding determined by the system's procedure and by Wade's rule. Emergence of the 'L' shape

6 - After one hundred and nineteen moves

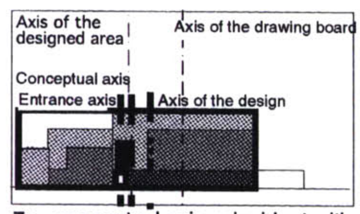
6a - The door axis became more important than the entrance axis

Fig. 112 (continued)
Wade's design process analysis

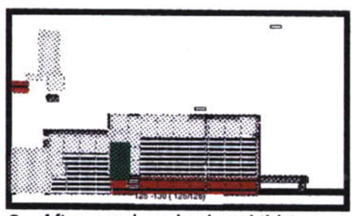
doorway (Fig. 7.112-6). When he did that, the axis of the door became an important reference itself, and his visual weight was so significant that it caused a conflict with the conceptual axis. Wade decided then to move the stairs to the right, which he did after he clad the left clear-story space and the porch (Fig. 7.112-7). By moving the stairs to the right, he diminished the weight of the door axis by counter-balancing it with the stairs axis, accentuating at the same time, the visual weight of the conceptual axis (Fig. 7.112-8). He then glazed the porch on the left which he had temporarily clad (Fig. 7.112-9). Then he glazed the central doorway, respecting the conceptual axis (Fig. 7.112-10). However, respecting the conceptual axis caused one to



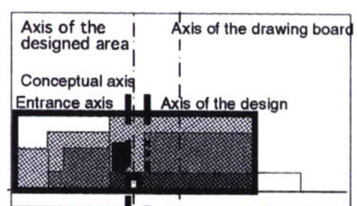
7 - After one hundred and twenty three moves



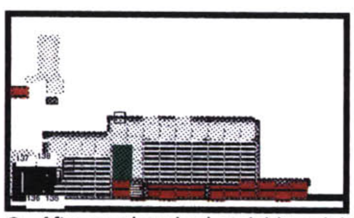
7a - conceptual axis coincident with axis of the main body of the house.



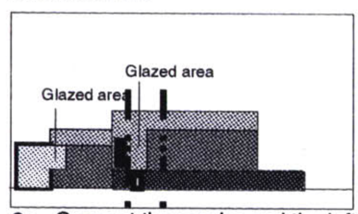
8 - After one hundred and thirty moves



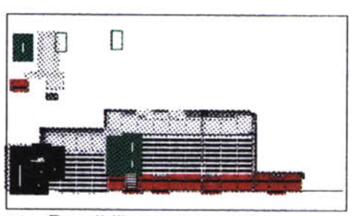
8a -The entrance axis moved back to the right, closer to the other reference axes



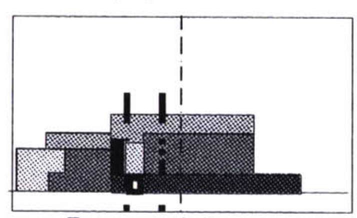
9 - After one hundred and thirty eight moves



9a - Connect the porche and the left 'clear storey' space.

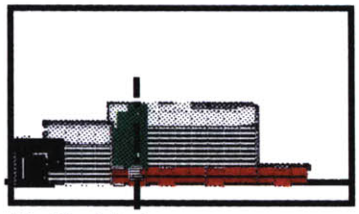


10 - Possibility attempted but rejected

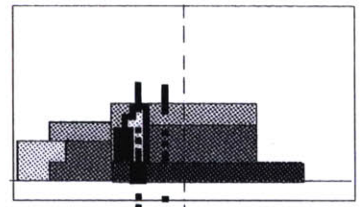


10a - Entrance axis between the door and the windows, distant from the center of the composition

Fig. 112 (continued)
Wade's design process analysis



11 - Final design:



11a - A compromise between contradictory rules.

Fig. 112 (continued)
Wade's design process analysis

perceive the facade as out of balance, since the conceptual axis was clearly the main axis of the design, and the weight on the right of that axis was greater than the weight on the left. Wade then rebuilt the glazing of the doorway, in such a way as to accentuate its axis so that it became more important than the axis of the door (Fig. 7.112-11). Since, this axis was closer to the axis of the design, and closer to the axis of the drawing board, the composition looked in a better balance.

In conclusion, the successful description of Wade's design process shows that two rules, one for diversity and another for balance, competing against each other shaped his design. Additionally, the description supports the validity of a theoretical model proposed for the balance rule that assumes the existence of different abstractions, and different reference axis. The description also shows that Wade was not able to design a balanced facade because he considered alternatively different abstractions, one aiming at creating a balanced facade (average background), and another aiming at balancing the facade within the drawing board (white background). Based on this fact, we argue that if we wish to design facades that are perceived as balanced without an external background we should use the average background model. We will now test the validity of the proposed model with Taylor's design process, and support the validity of the above argument.

b) Taylor's design process

The validity of the proposed theory, and the need for balance is also clearly illustrated by Taylor's response to Wade's design. The theory succeeds in explaining why Taylor's design looks better balanced than Wade's. As we saw, Wade compromised the possibility of making a balanced composition when he defined the conceptual axis too far on the left, too far from the axis of the drawing board. The axis of Wade's design expresses a compromise between several reference axes, similar to Thomas in the "The spoken game with abstract elements". However, the greater distance between references axis caused one to perceive Wade's design to be less balanced than Thomas'. When Taylor replied to Wade's design he had the opportunity to "correct" that flaw.

The calculation of the x coordinate of Taylor's reference and compositional axes are shown in Appendix B.4, the reference and compositional axes of Taylor's design are illustrated in Fig. 7.114, and the detailed analysis and interpretation of his design process is diagrammed on Fig. B.11. Recall that Taylor started his design by abstracting from Wade's design the features that he saw as significant (Fig. 7.113). He used then those features as rules in the development of his design. After he defined those rules, he decided to reverse Wade's composition in order to make his own composition more diverse. Look how he reversed Wade's composition in order to balance it. First, he made the composition clearly asymmetrical by moving the vertical glazed tower to the left, then he balanced the visual weight of the vertical tower with a long horizontal element. Finally, he placed a window right on the visual axis of the composition. The placement of that window is very significant. Recall that Taylor intended to place that window at the beginning, but that he gave up the idea because the wall panels would hide it. At the end of his design he forgot that he had intended to place the window, but he did not forget to place it. Without the

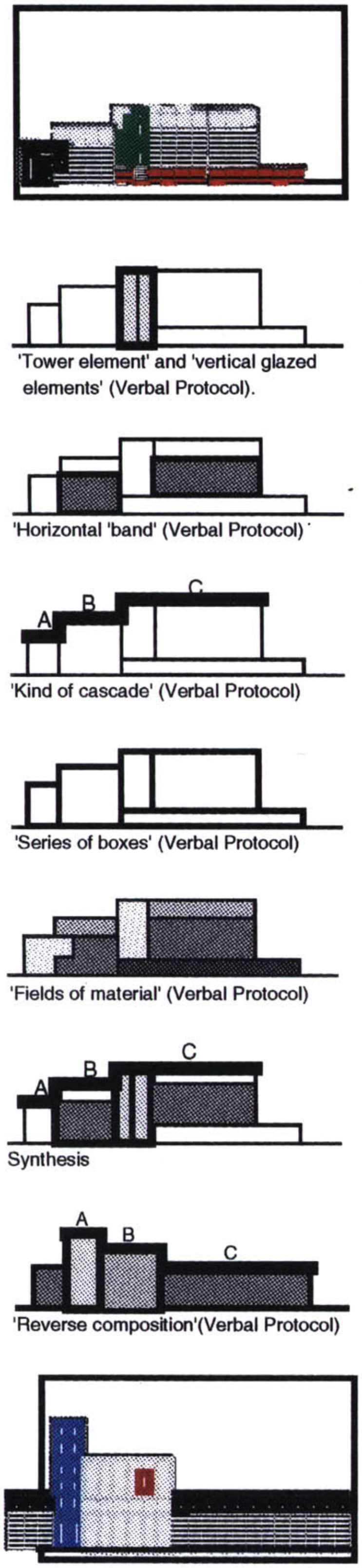


Fig.7.113
Taylor's abstraction of Wade's design

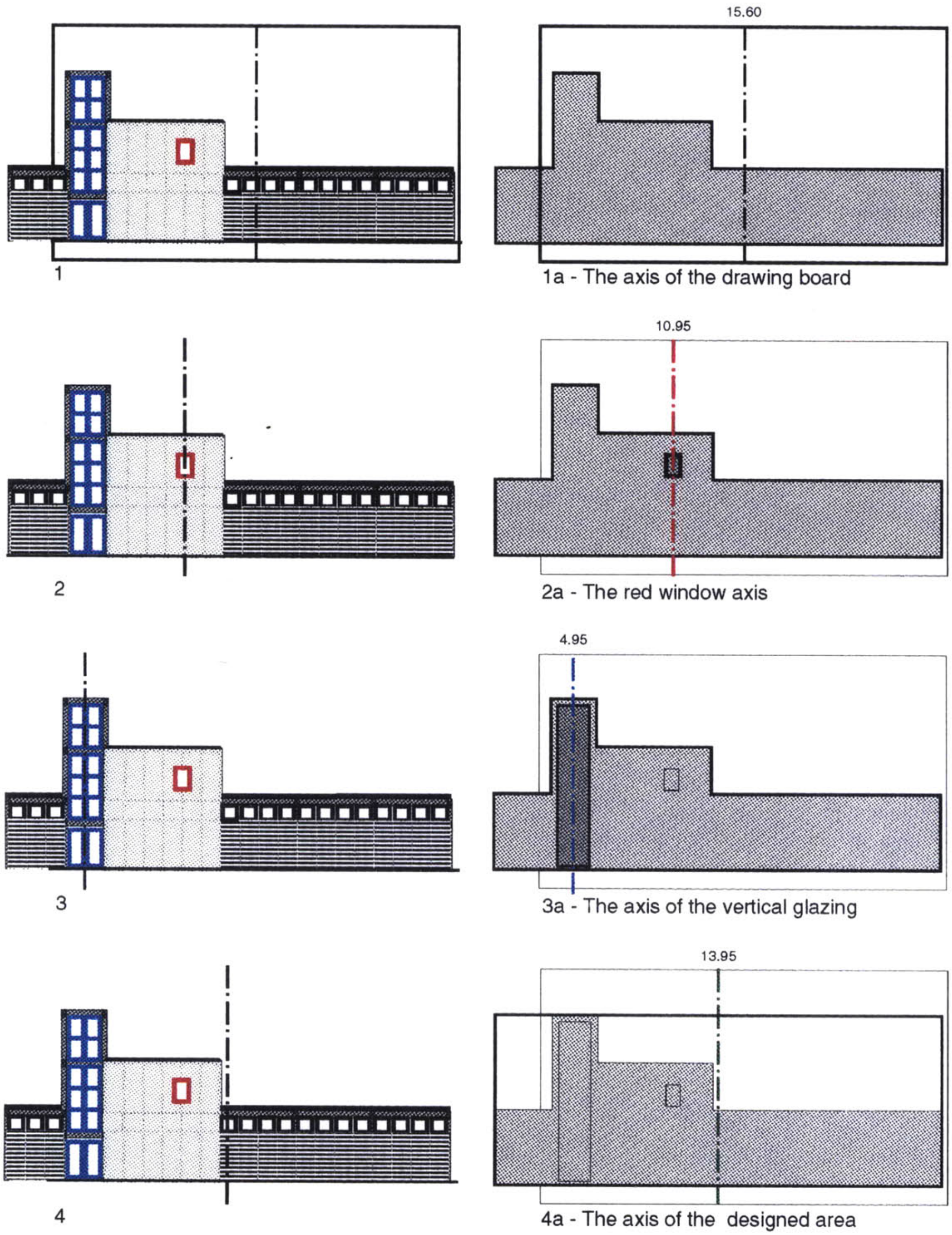
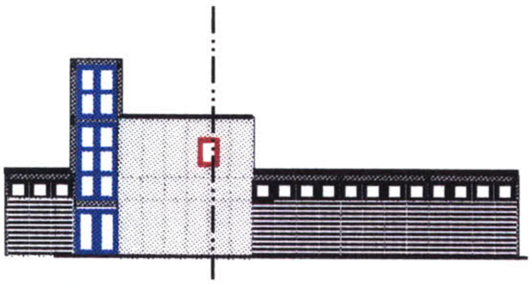
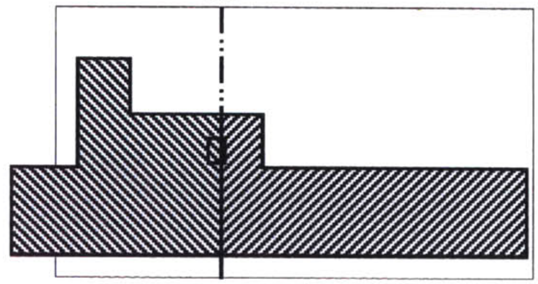
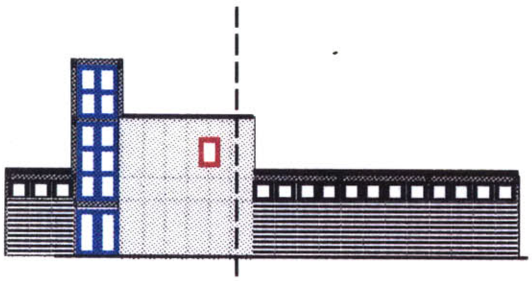


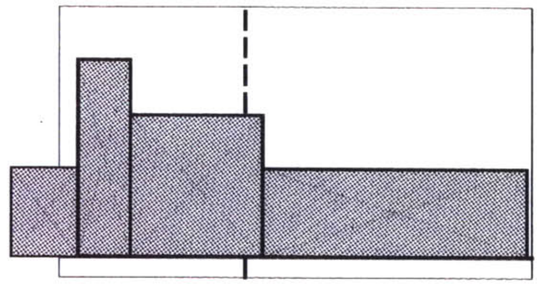
Fig. 7.114
Reference Axes of Taylor's design process


5



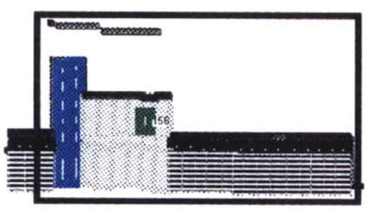
5a - The mid-area axis


6



6a - The compositional axis assuming that different colors have the same visual weight

Fig. 7.114 (contined)
Reference axes of Taylor's design process


1.- After one hundred and fifty six moves

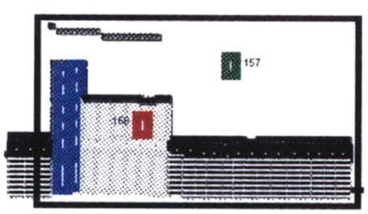
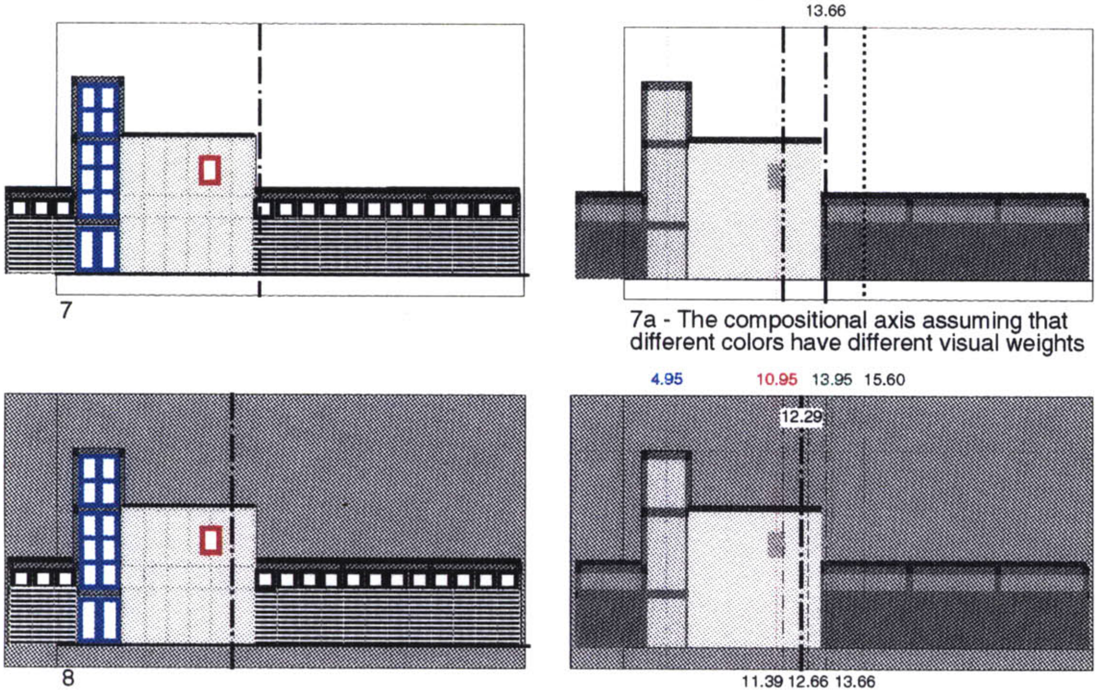

2.- After one hundred and fifty eight moves

Fig. 7.115
Taylor's design process

window, the axis of the glazed area was heavier than the virtual axis of the design. By placing the window, he strengthened the visual weight of that axis which clearly became the main reference axis of the design on the left, counter-balanced by the axis of the designed area on the right. The need to strengthen this axis was so important, that the placement of a green window was not enough; it was not different enough from the rest of the windows in the design (blue) to pop up (Fig. 7.115. So, he changed it to a red window. The compositional axis of the design is exactly between these two reference axes (Fig.7.116-8,8a). This compositional axis is the one in which its x coordinate was calculated by measuring the visual weight of each shape on the facade against all the other shapes, instead of against the white background. Therefore, Taylor's facade is itself balanced, unlike Wade's. Moreover, the facade plus the drawing board also look in



7a - The compositional axis assuming that different colors have different visual weights

8a - The compositional axis assuming that different colors have different visual weights measured against a background whose visual weight is the average of all the design's colors visual weights

Fig. 7.116
Compositional axes of Taylor's design process

equilibrium (Fig. 7.116-7,7a). In fact, the compositional axis calculated by measuring the visual weight of each shape in the facade against the white background is almost coincident with the designed area axis and is between the mid-area and the drawing board axes, the reference axes that one is likely to consider in this case.

In conclusion, the theory explains why Taylor's design looks in a better balance than Wade's: when considering either the facade itself, or the facade plus the drawing board, not only are the reference axes in each case closer to each other, but the correspondent compositional axes also are between them. Therefore, the theory seems to be a valid one.

The subjects exhibited a general trend towards vertical balance

We have seen in the discussion above how Wade and Taylor were concerned with balance when they were asked to generate diverse facades. In following, we will see that balance was also a concern in the other subjects' designs. However, unlike Wade's and Taylor's designs, the other subjects' concern for balance is reinforced by the use of symmetries, and so we do not need to build mathematical models of their designs to show how they were concerned with balance. I believe, nevertheless, that these models could be built.

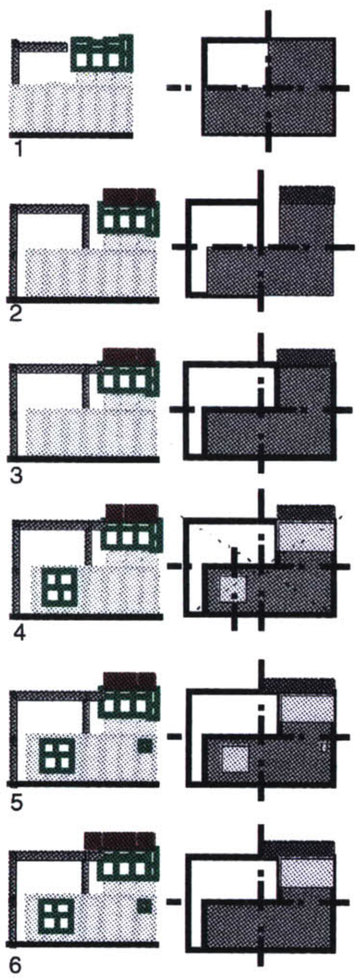


Fig. 7.117
Salvatore's design process analysis

Salvatore is the one of the designers whose concern for balance offers few doubts, since his concern for symmetry is very evident. His design process is analyzed in Fig. 7.117 from the symmetry and balance viewpoints. Salvatore saw his facade as the result of the deconstruction of a box to reveal the structure.

> *So, it will be this kind of terrace freeing the structure from this.*

However, he was not successful in his first attempt to attain this goal (Fig. 7.117-1), so he had to redo the design (Fig. 7.117-2 to 7). As a result, his design process went through two stages. In both stages, he designed an asymmetrical house but a symmetrical structure. The structural symmetry was important to perceive the facade in balance. Note how he needed to link the upper left structural bay to the upper right side of the house (Fig. 7.117-3). He also needed to balance the upper right glazing, with a big window on the lower left side, accentuating the diagonals of the house (Fig. 7.117-4). Then he also placed a small window on the lower right side, far away from the axis, in order to balance the heavy window on the right (Fig. 7.117-5). Note how he also needed to extend the roof to the axis of the house (Fig. 7.117-6), making symmetry more obvious. Salvatore designed an asymmetrical house, but all his moves were aimed at balancing

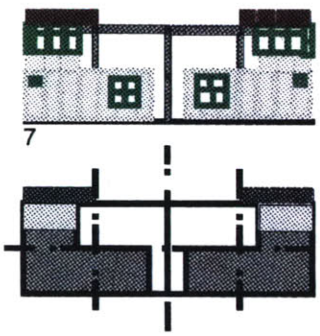


Fig. 7.117
Salvatore's design process

the composition as much as possible. In fact, if one abstracts the white background, one is able to see that the positive areas of his final design balance the negative ones, much like in the Yin and Yang symbol, and in Taylor's design (Fig. 7.117-7). However, his need for balance, and his bias towards symmetry were so strong that not satisfied with the balance he had achieved he said:

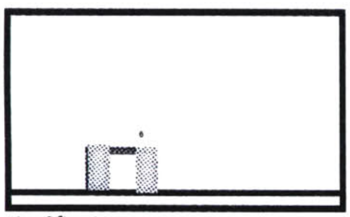
> *It's almost a temptation to reverse like this.*

And he suggested to mirror the house. Once the Design Tracer stopped he did perform his mirror operation making his facade totally symmetrical (Fig. 7.118-8). In the final discussion, when I asked him about the diversity of his design, Salvatore acknowledged the lack of diversity and said:

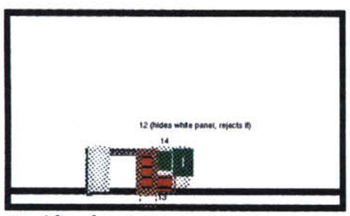
> *This a kind of... I like a kind of order, this doesn't mean symmetry. But I really dislike having all these windows with all different colors.*

In other words, not only did he acknowledge his need for order, but also his need to avoid symmetry. His bias towards symmetry was so strong that although aware of it he could not entirely escape from it.

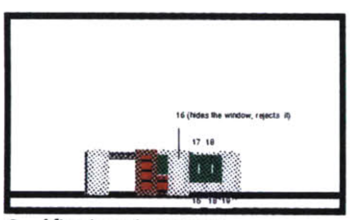
Ming, who was replying to Salvatore's design, did not exhibit as obvious a concern for symmetry as Salvatore's, but he was also concerned with balance and trying to avoid symmetry. For example, he designed a symmetrical gateway for his house (Fig. 7.118-1), but later on, perceiving its symmetry, he changed it (Fig. 7.118-2). Then, he continued to build the grounding floor in such a way that not only was its right side symmetrical but the entire grounding floor could be perceived as symmetrical, with a small vertical window accentuating the axis (Fig. 7.118-3). Then, he seemed to perceive the symmetry and added another wall panel to the design destroying the symmetry, but keeping the right side symmetrical (Fig. 7.118-4). Later on, after he had built the second floor (Fig. 7.118-5), he added another structural bay to the grounding floor, making it look almost symmetrical (Fig.



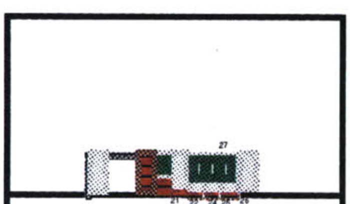
1 - After ten moves



2 - After fourteen moves

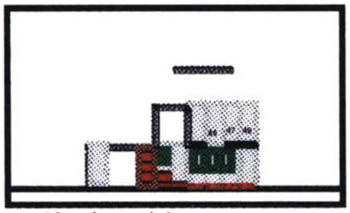


3 - After twenty moves

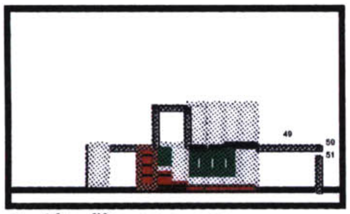


4 - After twenty seven moves

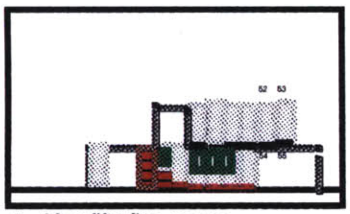
Fig. 7.118
Ming's design process



5 - After forty eight moves



6 - After fifty one moves



7 - After fifty five moves

Fig. 7.118
Ming's design process

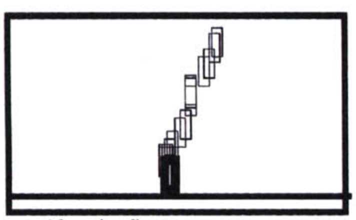
7.118-6). Then he seemed to perceive that and added to more panels to the second floor (Fig. 7.118-7). By comparing the design before he built that structural bay on the grounding floor, and the final design, one sees that despite that the fact he destroyed the symmetry of the design when he added the structural bay that structural bay is important to make us perceive the design in balance. Ming practically did a parametric variation of Salvatore's design. He designed a three-story house keeping Salvatore's verandah/room stepping pattern. However, he did not see his house as the result of the deconstruction of a box, but more like the result of an additive process. Salvatore acknowledged the fact saying:

> *It seems that for this part there has been more an additive process and not a process of doing the general, and then doing the holes.*

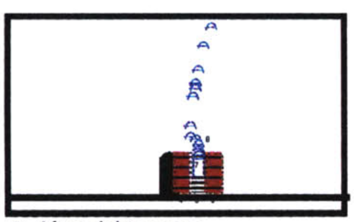
We saw how the structural integrity was important for the perception of balance in Salvatore's design. Ming, however, could not take advantage of that. Because of his three story house, he could have not explained the structural integrity of his design with the need for a pergola has Salvatore had done. A wide two-story pergola would have looked functionally awkward. Therefore, Ming needed to find another way to counter-balance the tall "L" shape of the facade. The stepping out structural bay gave him that perception.

In conclusion, all the designers exhibited a concern for order, used balance to give them the perception of order, and used symmetry to achieve balance. This behavioral pattern was also a feature amongst the non-designers. However, there were a few differences: first, non-designers used symmetry more obviously, second, they looked somehow freer.

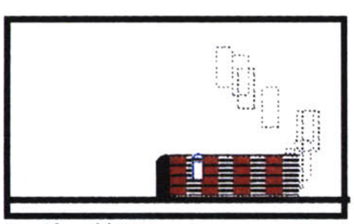
The use of symmetry to balance the design, on one hand, and the need to avoid it as much as possible in order to generate greater diversity on the other, has a paradigm in Pedro's design. Pedro started his design by placing the door at



1 - After the first move



2- After eight moves

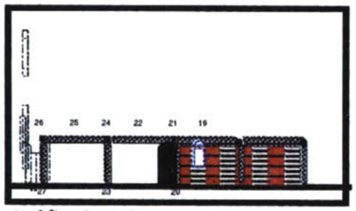


3 - After thirteen moves

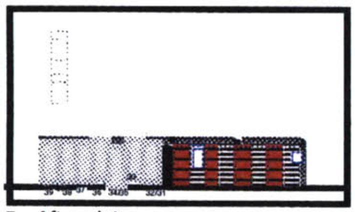
Fig. 7.119
Pedro's design process

the center of the drawing board (Fig 7.119-1), a clear move with the intention to generate a symmetrical composition. By placing the door on the center of the drawing board he avoided any future tension between the center of the design and the center of the drawing board. Pedro then built the right side of his house, by alternating a red-brick panel with a white brick panel in order to create a diverse wall. Then he placed his first window, realizing afterwards, that he had to build the structure. After Pedro built the ground floor structure, he noticed that the door could not be in the middle of the facade, contrary to what he had thought. He then placed the second window on the right facade, in a position symmetrical to the first one. Then, he moved on to build the left side wall. In order to make it different from the right side wall, he used whitewash panels. Then, he placed the windows in such a way that, despite using different windows, he placed them symmetrically. His trend towards symmetry is then clearly shown by the second floor he built that was a reverse composition of the ground floor. By doing that, Pedro re-established the symmetry, and thus the balance, of the whole house. His need to make the facade as symmetrical as possible is definitely shown by his last moves: he built the roof and placed a small window above the central door below. However, because the door was not exactly in the middle, he placed a small window on the second floor, near the center but slightly to the right, in order to counter-balance the effect of the position of the door. He then concluded his design by placing a small chimney on the right, strengthening the counter-balancing effect of the small window.

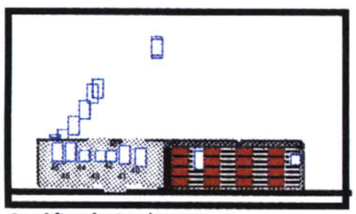
A comparison between Pedro's behavior and that of the designers, suggests that the designers were better able to balance the facade, but avoid symmetry. Because Pedro did not know to do this, he relied on symmetry. On the other hand, his instinct led him to counter-balance the asymmetrical placement of the door with asymmetrical placements of the window and the chimney.



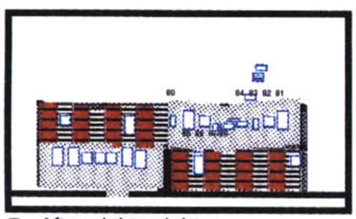
4- After twenty seven moves



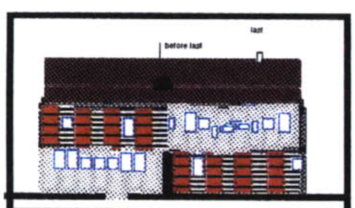
5 - After sixty moves



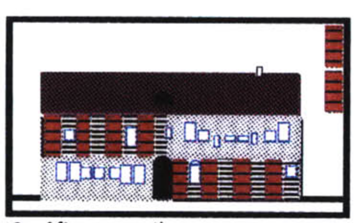
6 - After forty six moves



7 - After eighty eight moves



8 - After roof



9 - After correction

Fig. 7.119
Pedro's design process

Fig.7.120
Ana's design

The hypotheses raised by Pedro's design are supported by Ana's design. Ana's concern for symmetry is very clear in the housing prototype that she developed (Fig. 7.120). Note how the window and the door are symmetrically placed on each floor's facade. In fact, the concern for symmetry explains the development of such a prototype, and the rules that she developed with it. For, instance, we can understand why she considered the possibility of having a three-panel house, but not a four-panel house. She did not consider this possibility because she could not make the house symmetrical and at the same time, respect her rule "the windows should not be attached to the door" at the same time. Symmetry is also evident at other levels. For instance, it is present at a lower level, in the rules that she developed to detail the windows. It also present at a higher level, when she designed the ground floor of her second house (recall Fig. 7.66). However, symmetry did not constrain her design of the entire street. We can understand this fact if we recall our discussion in Section 7.2.11. According to what she said then, Ana did not constrain the entire street to symmetry, because she did not treat her design as a whole. In other words, she did not really try to balance the street. I argue now, that the fact she avoided symmetry at this large level is positive for our perception of her street facade as diverse[7]. By doing this, she

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[7] I would, however, argue that she did try to achieve a balance between the designed and the non-designed areas of her design, . They

maintained a considerable degree of independence of each house's order from the order of the street.

In conclusion, all the subjects, designers and non-designers, exhibited a trend towards vertical balance. This trend informed the development of their design processes, and seemed to constitute a form of ordering the diverse elements they introduced in their designs. In their struggle for vertical balance, non-designers tended to use symmetries, whereas designers were more successful in achieving vertical balance without symmetry.

Horizontal balance and background theme

The model developed for horizontal balance on the results of the experiment with abstract elements can be applied to facades

In Section 7.1.8 of the discussion of the "Spoken game with Abstract Elements", we showed how Thomas divided his composition into *infill* and *framework* and, how he tried to order his composition by making an ordered *framework*, and how he ordered the *framework* by making it horizontally and vertically balanced. In addition, in Section 7.1.9, we proposed a mathematical model for the perception of horizontal balance in a *framework,* based on the calculation of the average height of its elements, and drawn from an analogy with music, in which the *framework* constituted a *background theme*. In this section, we will argue that in the "Spoken Game with Architectural Elements" there is also present the idea of a *framework*, that the subjects also exhibited a trend to balance this framework, and finally, that the mathematical model proposed for the perception of a framework's balance in an abstract composition is also valid for facades.

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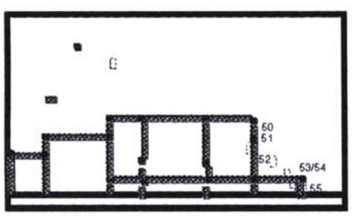
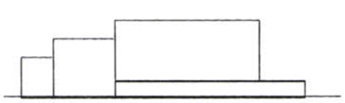
seem to complement each other, like black and white areas in the Yin and Yang symbol. This balance, however, does not seem to disturb our perception of the diversity of her design.

At a first glance, it seems difficult to compare the "Spoken Game with Architectural Elements" with the "Spoken Game with Abstract Elements" in terms of horizontal balance. In fact, we can raise two different arguments against such a comparison. These arguments are as follows. First, unlike Thomas' composition, the facades of the "Spoken Game with Architectural Elements" did not have any apparent visual separation between *infill* and *framework*. In fact, there was not any single color theme of disperse elements repeated throughout the facade. Second, how can one consider a facade horizontally balanced, if in architecture is difficult to have buildings whose area above the horizontal middle axis of the facade is equal to the area below? In fact, the area below tends to be greater because the bottom profile of the buildings follows the ground line, whereas the top profile can vary freely. Despite the strong argument, I will counter-argue and demonstrate how a comparison is possible.



1 - The structure

2 - The infill



3 - 'Series of boxes' (Verbal Protocol)

Fig. 7.121
In some designs, such as Wade's design, there was an actual separation between framework (1) and infill (2), as Taylor's abstraction of his design confirms (3)

In the designs of the "Spoke Game with Architectural Elements," there is also a separation between *infill* and *framework*. I support this argument on three points. First, in some designs the separation is real and embodied by the separation between structural and cladding elements (Fig. 7.121-1, 2). This separation inclusively caused a division of the design process into two stages: one to build the structure, and another to clad it. Second, in the cases where no structural elements were used, their existence was, nevertheless, implicit. For instance, some subjects said that they would place no structural elements where they were not to be seen, but they would assume their existence anyway. Finally, I argue that the idea of a *framework* is more than a mere representation of a physical structure. It also represents an abstraction about the forms themselves. In this abstraction, forms are reduced to their essential parts and then, in their turn, these parts are reduced to their contour. Recall, for instance, Taylor's abstraction of Wade's design (Fig. 7.121-3).

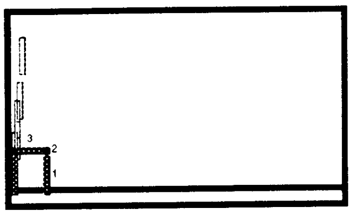
In this process, the existence of a single color is not required, since there are other common factors that can support this abstraction such as the fact that all the framework's forms represent walls. Additionally, the existence of adjacent shapes is not an issue as long as one can consider the existence of different shapes with different heights. The argument against the possibility of considering the existence of a framework is, thus, overcome. In the design of facades, the framework or background theme is constituted by the volumes that form the facade.

The argument, about the perception of horizontal balance in a design with a varying top height and a constant bottom can also be defeated. Recall that the calculation of the average height of Thomas' composition resulted from the calculation of a top average height, and the calculus of a bottom average height. I argue that in a design where the bottom height is constant, it is acceptable to consider that it does not have any influence on the perception of the total average height of that design. As a result, the perception of horizontal balance in such a design depends exclusively on the variation of its top height.

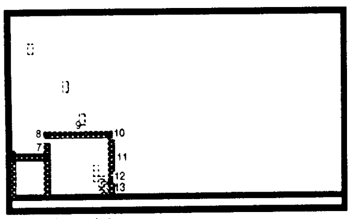
I will show in the following that the considerations raised above permit us to identify in the "Spoken Game with Architectural Elements" moves towards balance similar to those found in the "Spoken Game with Abstract Elements," and to successfully apply the mathematical model then developed to the design of facades. In my demonstration, I will use again Wade's and Taylor's designs.

a) Wade's design

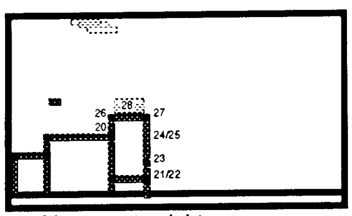
Recall Wade's design process. Look how Wade, after defining volumes of increasing height, and especially, after designing a long tall volume, designed a very short narrow volume (Fig. 122). It seems that he, somehow, needed to lower



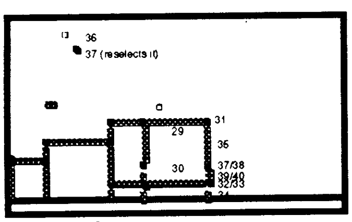
1 - After five moves



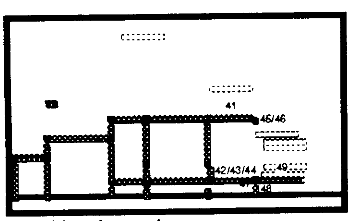
2 - After thirteen moves



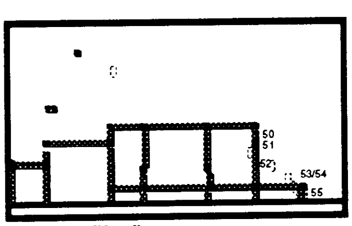
3 - After twenty eight moves



4 - After forty moves



5 - After forty nine moves



6 - After fifty five moves

Fig. 7.122
Wade's design process

the middle height level of the facade, because it had been at a very high level for too long. Notice that he could not design a longer final volume because it was supposed to be a porch's grounding. So, in order to considerably lower the average level he had to design a very low volume.

In fact, after the porch grounding's volume was added to the facade, the average height level reached such a level that it corresponded to the middle level between the previous shortest volume (the first one) height, and the tallest volume (the third) height (Fig. 7.122). That level is also coincident with the height of the second volume. Balance was thus replaced and achieved much in the same way as in Thomas' design process. The average height level represents an imaginary line in relation to which the areas of facade above and below are exactly the same.

If we recall the analogy with tonal music, proposed in Section 7.1.9, we will be better prepared to understand Wade's behavior. In this analogy, we considered that horizontal balance could be compared to the development of music around a central tone or key. In fact, before Wade built the porch's grounding, we were unsure about the key of his facade. On one hand, we were led to think that it was the height of the second volume, around which the height of the other two volumes seemed to gravitate. On the other hand, it seemed higher since the heights of the existing three volumes were progressively increasing. When Wade built the porch's grounding in the way he did, he destroyed all doubts, confirming the height of the second volume as the key or, in other words, confirming that height level as the reference axis. The development of his facade was converging towards *the moment of repose* mentioned by Stravinsky. It seems that his *statement* —the visual impression he wanted to transmit with his facade—was then complete. The parallel with music and language could not be more obvious, as one can acknowledge by reading the following excerpt from the musical textbook by Machlis.

We can examine the structure of a melody in much the same way we analyze the form of a sentence. A sentence can be divided into its component units or phrases; the same is true for a melody. A phrase in music, therefore, just as in language, denotes a unit of meaning within a larger structure. The phrase ends in a resting place or cadence, which punctuates the music in the same way that a coma or period punctuates a sentence. [...] One tone serves as the home base, around which the melody revolves and to which it ultimately returns (Machlis, 1990)

Amazing Grace (early American melody)

Four text phrases = four musical phrases

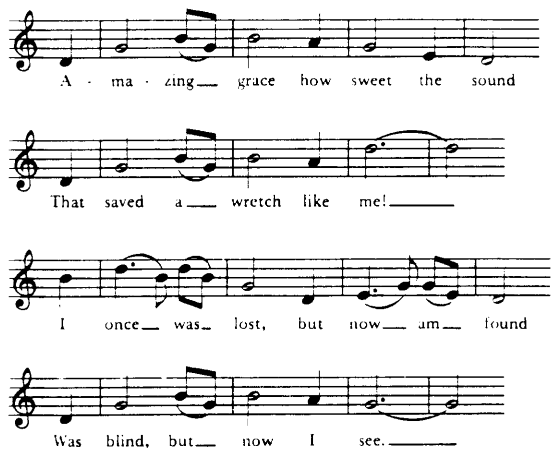
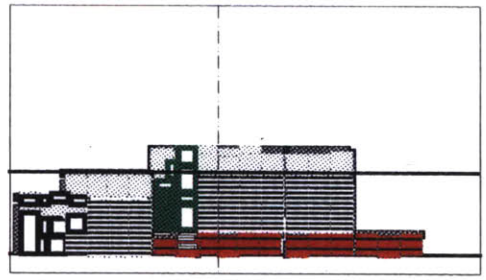


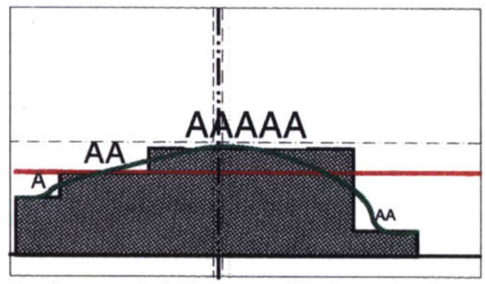
Fig. 7.123
The structure of a melody

In conclusion, with the addition of his porch's grounding, Wade's design became a complete statement (Fig. 7.124). Wade's design, however, has two flaws: first, it is not vertically balanced, and second, it does not have a climax. In fact, unlike Thomas' framework in which the areas to the left and to the right of the middle designed area axis were also the same, the area of Wade's volumes do not meet these conditions (Figs. 7.124-4). In order for Wade's design to have that quality, the volume of the central door-way, for instance, would have to be higher. Its height would have to reach the level indicated in Fig. 7.124-4. If he had that height, his facade would also have a climax. The existence of a climax in music is rather important as explained by Machlis:

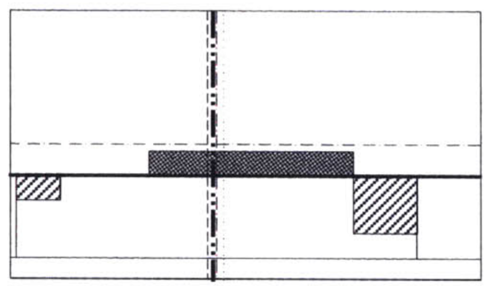
A melody has to be carefully shaped in order to maintain the listener's interest. What makes a striking effect is the climax, the high point in a melodic line that usually represents the peak of intensity. The climax gives purpose and direction to the melodic line. It creates the impression of crisis met and overcome.



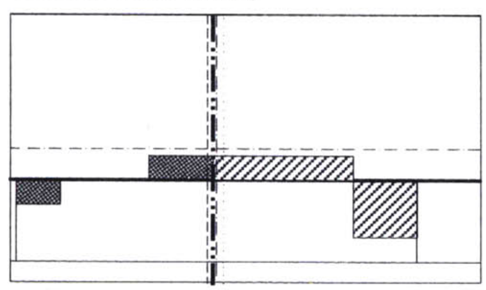
1 - Wade's facade: the average height line and the mid-area axis



2 - Average height line and horizontal axis of the drawing board (Wade)

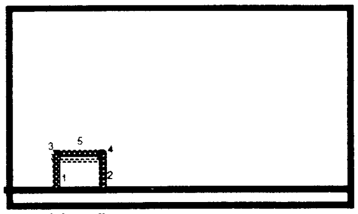


3 - The average height line of the facade divides the areas defined by the facade in such a way that areas above area equal to the areas below (Wade)

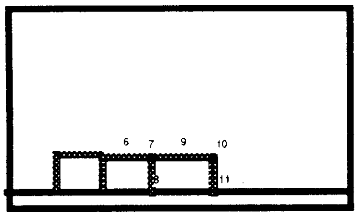


4 - The mid-area axis does not divide equally the sum of the areas above and below the average height line to its left and to its right

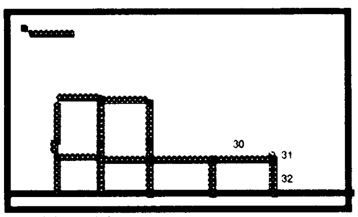
Fig. 7.124
Average height lines and horizontal balance of Wade's design background theme



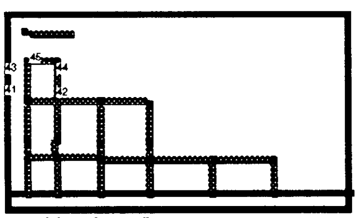
1 - After five moves



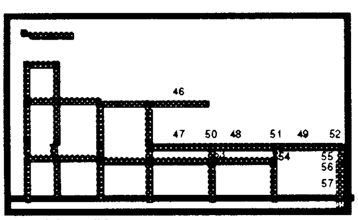
2 - After ten moves



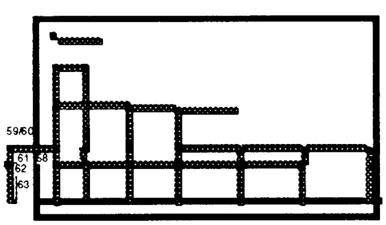
3 - After thirty two moves



4 - After forty five moves



5 - After fifty seven moves



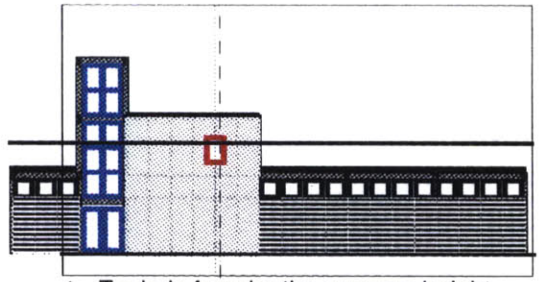
6 - After sixty three moves

Fig. 7.125
Taylor's design process

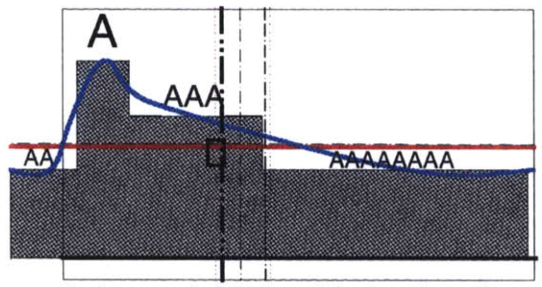
I argue that the existence of a climax in the design of facades is important. The arguments that the existence of both horizontal and vertical balance, as well as climax, in the design of facades are supported by Taylor's reply to Wade's design. In order to demonstrate these arguments, I will show that Taylor, beyond designing a facade whose *background* is in horizontal balance, he also corrected the flaws of Wade's facade, making a background in vertical balance and giving it a climax.

b) Taylor's design

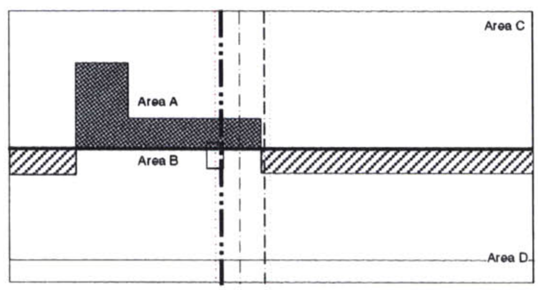
In a similar way to that of Wade's, Taylor designed a short volume after he had designed two taller ones, counter-balancing the effect of these two volumes. However, the calculation of Taylor's facade average height shows that unlike in Wade's facade, its height does not coincide with the height of any of the volumes that constitutes it (Fig. 7.125). This raises the problem of which was the horizontal reference axis of his design. However, the average height line seems to be key since the facade seems in horizontal balance relatively to it. This means that the average height line must be very close to the reference axis. The fact that the horizontal mid-axis of the drawing board is coincident with that axis, allows us to consider it as the reference axis. On another hand, the axis of the red window is also very close. We have already saw how the placement of the window definitely caused one to perceive the entire facade in vertical balance by turning its axis into the main reference axis on the left side of the design. I argue now that the placement of that window also highlighted the horizontal mid-axis of the drawing board as the horizontal reference axis, or provided itself this reference, causing one to perceive the facade in a clear horizontal balance. In other words, the placement of the window confirmed the average height line as the horizontal compositional axis. The facade's background is thus in horizontal balance (Fig. 7.126).



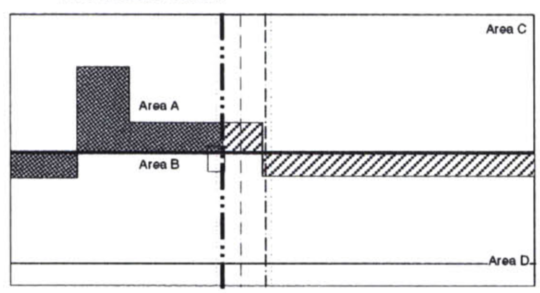
1 - Taylor's facade: the average height line, the mid-area axis, and the red window axis.



2 - Average height line of the facade and horizontal axis of the drawing board (Taylor)



3 - The average height line of the facade divides the area of the virtual drawing board in such a way that areas above area equal to the areas below



4 - The mid-area axis almost divides equally the sum of the areas above and below the average height line to its left and to its right

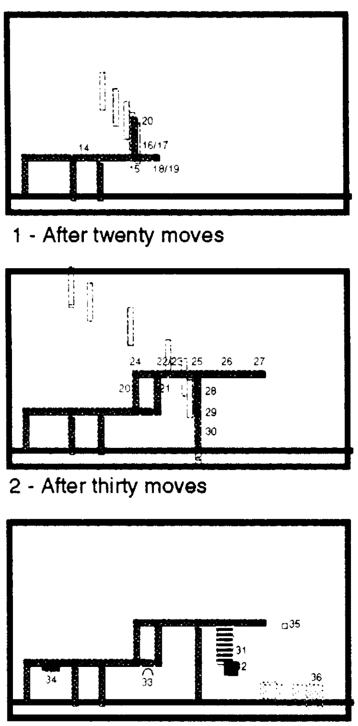
Fig. 7.126
Average height lines and horizontal balance of Taylor's design background theme

Additionally, the measurements of the areas to the left and to the right of the window, which are very similar, show that the facade's background is also in vertical balance (Fig. 126-4). As a result, Taylor's facade is in both horizontal and vertical balance, unlike Wade's. Finally, the variation of the facade's height also has a clear climax, in the glazed volume. Interestingly enough, the height that Taylor gave in his facade to this glazed volume is about the same height that we thought Wade's glazed volume should have in order to be in vertical balance. If we recall that Taylor's glazed volume resulted from his abstraction of the glazed central door-way of Wade's facade, we can argue that Taylor replied to Wade in such a way that he corrected the flaws of Wade's facade in terms of equilibrium and climax. And so, we can support the argument that these features are important in the design of facades. In addition, we can also sustain that the mathematical model proposed to describe horizontal and vertical balance of the *framework* seems to be accurate.

c) The other subjects

The concern for horizontal balance was not as evident in the other subjects designs as it was in Wade's and Taylor's designs. It was, nevertheless, present in some of those designs, as I will show in following.

Pedro's design does not have any variation in terms of height. It is, therefore, absolutely leveled and so it also is horizontally balanced. Ana's, Salvatore's and Thomas' second design have only two different heights. Hence, they exhibit a minimum variation, and so it is as difficult to hold that they were horizontally balanced as to maintain that they were varied. Nevertheless, Thomas' first design, Ming's and Joan's designs express clearer concerns for horizontal balance. Thomas did not finish his first design. I asked him to stop designing when he told me that he was not designing a building. He insisted, nevertheless, to place a last element (Fig. 7.127). Note how

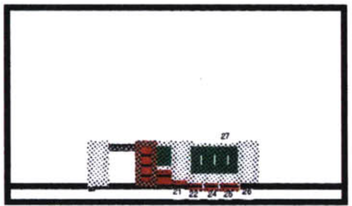


1 - After twenty moves

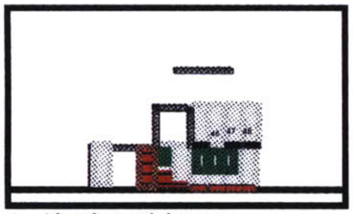
2 - After thirty moves

3 - After thirty six moves

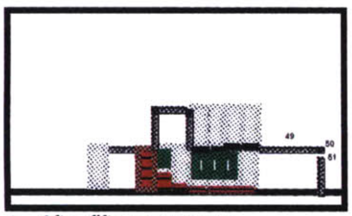
Fig. 7.127
Thomas's design process (1st Attempt)



1 - After twenty seven moves



2 - After forty eight moves



3 - After fifty one moves

Fig. 7.128
Ming's design process

Thomas' last move was the placement of a small element on the lower right corner of the design. I would argue that this move represents an attempt to horizontally balance the design. In a similar way, I would argue that the construction by Ming of a shorter structural bay on the right side of his design, after he designed two taller volumes (Fig. 7.128) is an attempt to horizontally balance the facade and to make it achieve the *point of repose* . The effect is especially perceptible after Ming added a third floor to his design. Finally, June also exhibited a tendency towards horizontal balance. She was the subject who built the highest number of volumes with different heights. She also alternated the construction of short volumes with the construction of a taller ones. It seems that she was trying to vary the volumes heights, but maintaining the average level. Hence, she was also concerned with horizontal balance.

In conclusion, all the subjects who were concerned with varying the height of the volumes were also concerned with horizontal balance. This concern seemed to constitute a form of ordering the diverse heights they created in their designs.

7.2.19.4 *Static* and *dynamic* perception of balance

How is order perceived?

2

The perception of each type of balance operates differently due to memory constraints

Vertical balance is closer to the way we look at a building on a street, whereas horizontal balance is closer to the way we look at one building after another when we move along a street

In the discussion above, we have referred to horizontal and vertical balance. In the discussion that follows I emphasize that the perception of each of type of balance seems to operate differently. The perception of vertical balance often requires the observer to see the entire object from where he is standing, whereas horizontal balance can be perceived as he moves along. I argue that the perception of vertical balance is the way we look at a small building, whereas horizontal balance is closer to the way we see several buildings when we move along a street. Finally, I argue that these differences should be taken into account in the design of a street facade.

Motion affects the perception of balance

These differences should be taken into account in the design of a street facade

Single buildings should be in vertical balance, whereas a row of buildings should be in horizontal balance

Recall Thomas's experiment with abstract elements discussed in Section 7.1. Note how he basically achieved vertical balance by alternating the placement of an element on the left with the placement of an element on the right (Section 7.1.8). There were few exceptions to this procedure which occurred when he placed elements on the same side of the screen one after another. The exceptions were prompted when the color or shape of the elements he had already placed required him to correct the equilibrium of his design. Note also how the procedure he used to achieve horizontal balance was different. He essentially achieved horizontal balance by placing the framework elements one after another from the left to the right. There was only one exception to this procedure when his placement the last framework element. However, this placement was prompted by the need to vertically balance the framework. Finally, note how the subjects of the "Spoken Game with Architectural Elements" also followed similar procedures in their struggle for each type of balance, thereby confirming the observations in Section 7.1 on "The Spoken Game with Abstract Elements." Recall, for instance, how Wade clad the extremes of his facade only after he clad its center, or how he built a short volume after he successively built three taller ones. I argue that the different procedures used to achieve the different types of balance are due in turn to the different way each type of balance is perceived which are prompted by memory constraints, as explained below.

The perception of vertical balance requires one to look alternatively at each side of the object looking for counter-balancing elements. Therefore, it requires one to see the whole object at the same time or to quickly move back and forth from one side to the other. However, if the object is not symmetrical and it is so big that the observer cannot see it entirely, he is not able to judge its vertical balance, even by moving back and forth. In fact, if the object is not symmetrical it is difficult to find counter-balancing elements, and the observer needs to store the information about the elements on both sides until he finds counter-balancing groups of elements. Nevertheless, vertical balance requires one to keep in mind many attributes such as the color, size, and position of all the shapes in the design. Since, one has a limited short-term memory, as pointed out in Sections 7.1.1 and 7.2.11, it is difficult to store all this information. Therefore, vertical balance can be perceived only by looking at the entire composition, and so is in a static position. In this situation, vertical balance is experienced directly eleminating the need to memorize the attributes of each element. The perception of horizontal balance is not so constrained by such short-term memory limitations.

The perception of horizontal balance can be experienced by looking sequentially at the object from one side to the other. Therefore, it does not require one to see the whole object at once. As explained Section 7.19.3, horizontal balance needs one to abstract few attributes of the object from the design, such as the height and length of the volumes that form a facade. One can then easily memorize this information compared to the numerous information required for vertical balance. As a consequence, even if the object cannot be seen entirely at once, it is possible for the observer to perceive its horizontal balance by moving along the object.

Nevertheless, since short-term memory is limited it also limits the amount of information required for perceving horizontal balance. If one has to remember so many attributes, one will be unlikely able to perceive horizontal balance. This is the case of a composition formed by many elements, in which horizontal balance is perceived only when one sees the last element. However, one will certainly be able to perceive horizontal balance in a composition formed by many elements, if horizontal balance is cyclically achieved. Let me recall the analogy between the visual perception of horizontal balance and tonal music in order to better illustrate this argument. In music, the structure of a melody is made of units called phrases, as we have already mentioned in Section 7.19.3. According to Machlis:

> *A phrase in music, (...) just as in language, denotes a unit of meaning within a larger structure. The phrase ends in a resting place or cadence, which punctuates the music in much the same way that a comma or a period punctuates a sentence. (Machlis 1990)*

Therefore, each phrase is a part of the melody that is balanced around the central tone. In a visual composition, each phrase would correspond to a part in horizontal balance. Machlis, elucidates that:

> *The cadence is where a singer stops to draw breath.*

In a visual composition, the cadence would correspond to the point where the observer, having perceived a part of the composition in horizontal balance, could empty his short-term memory of all the information he needed for that perception, allowing space for the information about the rest of the composition. Then, he would have to store only the position of the horizontal balance axis, and continue to appreciate the rest of the composition having this axis as a reference.

In conclusion, vertical and horizontal balance are perceived differently, these differences being connected to the amount of information required for the perception of each one, are constrained by short-term memory limitations. Because the perception of vertical balance requires an object small enough to be seen in its entirety by a static observer, it is closer to the way we look at each building on a street. Because horizontal balance can be perceived by an observer in motion, which implies a time sequence, it is closer to the way we look at one building after another, when we move along a street.

It seems rather important to take into account the differences between these two perceptions in designing facades. These differences suggest that one should not constrain the design of a street with the need to achieve vertical balance, since short-term memory limitations will limit the observer's ability to perceive this balance. It is, nevertheless possible for him to perceive horizontal balance. Since he aims for balance, the design of a street should be constrained by the need to achieve this balance. On the other hand, one should constrain the design of a single building with the need to achieve vertical balance.

7.2.19.5 Extended application of the concept of horizontal balance

It was shown some experimental evidence that horizontal balance was used by designers to harmonize the variation in height and width of a row of volumes

In addition, I propose to use horizontal balance in the creation of pleasant variations of other attributes and shapes in the design of a row of facades, such as wall colors and window sizes.

In previous sections, I discussed how balance seemed to allow the co-existence of diverse elements in a way that are pleasantly perceived by a human observer. Based on the results of the experiment with abstract elements, I showed how the perception of horizontal balance is related to the variation of different heights of shapes around a central height used as reference, in a composition. Then, based on the results of the experiment with architectural elements I also showed how the perception of horizontal balance is related to the variation of different heights of volumes around a central height taken as reference, when the composition is a facade. In both cases, the perception of horizontal balance required the observer to neglect some features and focus on others. The features on which the observer should focus were the heights and the widths of certain shapes, the framework elements in the first case, and the building walls in the second. This model for horizontal balance was based on an analogy with tonal music in which height was the pitch, and width represented the amount of time each note was played. Finally, based on the results of both experiments, I argued that the perception of horizontal balance is the way we look at one building after another when we move along a street, and I proposed that horizontal balance is a way to harmonize the variation of different buildings heights in the design of a street facade.

I believe that the concept of horizontal balance is not only applicable to the harmonization of a sequence of buildings with different heights. I would argue that the height and the width of the facade of each building are not the only attributes and elements to which horizontal balance can be applied to create a pleasant variation. In fact, I believe that horizontal balance might be used to harmonize the variation of other attributes and shapes, as far as they their sequence has a scale that enables it to be apprehended by an observer in the dynamic way described for the perception of horizontal balance. I include, for instance, the sequence of wall colors in a row of houses, and a sequence of windows with varying sizes and colors located at the same horizontal level. In fact, the color weight indexes proposed in this study (Section 7.1.10) provide a suitable way to measure color in relation to a tone taken as reference. Again, to use the analogy with music, color would be like the pitch of a note in a music composition, whereas the size of the wall, or those of the windows, would be like the *time* interval during which a given *pitch* (color) was played. Each sequence would then be like a different theme, played by a different instrument. The abstraction that we found associated to horizontal balance would be the neglecting of the other attributes different from the ones required for the perception of the theme selected.

In conclusion I propose an extended use of horizontal balance in order to create pleasant variations of attributes of elements that are common to the different facades of a row of houses. I believe that further experimental studies will be able to verify the validity of this extended use of horizontal balance. I will, nevertheless, introduce its use in the Street Facade Generator, proposed at the end of this thesis.

7.2.19.6 Scale and function

How is order perceived?

Scale, the way a system is defined, the function assigned to that system, and cultural aspects affect the perception of order

In previous sections, we saw how order is perceived through logic, orderliness, and balance. We also identified some factors that affect the perception of these types of order in a design, formed by distinguishable shapes, such as the size, color, location, and repetition of its elements or shapes. These factors, although dependent on the ability of the observer to perceive them, can be considered factors inherent to the object. Additionally, we referred to other factors that also affect the perception of order such as the short-term memory and the state of motion of the observer. Unlike other factors, memory is clearly a factor connected to the observer instead of to the system. Motion in turn, depends both on the observer and on the size of the object. In this section, we will mention other factors that affect the perception of order that depend both on the observer, and on the object. Namely, we will see how the perception of order depends on how we define a system, on the function we assign to it, on the scale we decide to focus on, and ultimately on cultural factors. The influence of these factors reveals how relative and subjective it is the concept of order, and it also demostrates how important is to carefully frame the design to obtain the desired order.

I will start the discussion in this section by referring to the concept of order in physics. Order is used in physics to describe the effects of two general and universal tendencies observed in the physical world. One is the tendency observed in isolated systems to acquire the most orderly possible form under given conditions. It is usually described as the tendency of systems to move towards the most ordered state and remain in that state until external conditions change. This phenomenon is observed, for instance, in the formation of snow crystals and arrangement of molecules. The other is the principle of increasing entropy, usually described as a the tendency observed in isolated systems to move towards disorder. It seems that there is a contradiction between these two physical principles. The contradiction, however, is only an apparent one. As Rudolf Arnheim put it in his essay Entropy and Art: *the definition of entropy as a measure of the disorder of a system is in need of considerable interpretation.* I add that the contradiction reveals how scale affects the perception of diversity. The following example adapted from Arnheim's essay will be useful to explain how.

Imagine a container, divided in two halves by some device. On each side of the container is a liquid of a different color: one is black and the other is white. At this stage, the system's order is very clear to a human observer: black liquid on one side, and white liquid on the other. Imagine now that we take out the device that divides the container. The two liquids will run to each other and start to mix. At a certain point, there will be a greater amount of white liquid on the side of the container where it was initially placed, and vice-versa for the black liquid. In the middle somehow, co-exist particles of white and black liquid, randomly distributed. At this stage it seems that the order of the black particles clashes with the order of the white particles. The system will then continue to evolve until it reaches a certain point at which a human observer sees what he describes as gray liquid. At this stage the system achieves a state of balance. This state corresponds at a microscopic level to a state in which the probability of finding a white or black particle at a given point of the liquid is exactly the same. In other words, the system reached a point of homogeneous random distribution of white and black particles. Since homogeneity is orderliness, and orderliness is a manifestation of order, we have to conclude that the system became ordered and not disordered.

The contradiction is apparent because we and the physicists have different things in mind. We emphasize how the system looks homogeneous to a human observer, and the physicists base their defintion of disorder on probability. They define disorder as the number of possible arrangements between the particles of the two liquids, whereas the human observer perceives the liquid as having one arrangement. They do not exclude the possibility of the system freely evolving to a state in which the black particles will again be on one side and the white particles on the other. Nevertheless, the possibility of this happening is infinitely low. Order is, thus, defined in Physics as an improbable arrangement. If we could shrink ourselves to a size in which we could perceive the different particles, we would not be so insensitive to the possible changes of arrangement between them. This would be the case if our container became the entire universe. The physicists, using also the principle of increasing entropy, say that the universe is moving towards chaos. It is not difficult to agree with them when we think about stars that explode, solar systems that collapse, and the spread of their matter within an increasingly larger area. The universe, like the system in the container, it is said to be moving towards a state of equilibrium. It is, therefore, moving towards a state at which if we were big enough we would perceive it as homogeneous as the gray liquid in the container.

The two examples given above illustrate how scale is, in fact, a major factor affecting the perception of order. They also illustrate how the definition of order depends on which elements we decide to consider as part of a system. If we focus on a certain smaller part of a larger system, this part might be evolving towards an increasing order. If we focus on another small part or on the entire system, the reverse might be happenning. The way a system is defined is often connected to a function we decide to ascribe to the system. In fact, among current definitions of order there is the one that associates order to a state of good-functioning of a system. According to this definition, order is defined as *a system function according to definite laws or rules* (Webster's Dictionary). This concept of order is used, for instance, in the biological and medical sciences, where a disease is often called a disorder. In fact, the invasion of a human organism by some microrganisms that jeopardize the function of one or more of its subsystems, and ultimately, its survival, is called a disorder. Note how the concept of order and disorder depends on which system we are concerned with, and on the function we assign to it. This use of the concept of order is also common beyond medical and biological sciences. From our discussion, we can infer that, the same arrangement of a system's elements might be considered ordered from a certain viewpoint and disordered from another one. Since the concept of order implies a judgement of value about the function of a given system, it is not hard to imagine that it also depends on cultural values. What for a certain society at a certain point might be considered positive, for another might be considered negative.

In conclusion, order is relative and subjective. It depends on scale, on the way a system is defined, on the function assigned to the system, and on cultural bias. It is, therefore, rather important to choose the scale at which we want order to be perceived, to select the elements we want to be part of the system, to guarantee that the system perfforms its function, and to take into account the cultural values. This matter will be further discussed in the next section.

7.2.16.3 Why Order?

The subjects' tendency towards order mirrors a similar tendency prevailing in the physical world

In the previous sections we came to the conclusion that when asked to generate diversity, the subjects exhibited a tendency towards order. However, a question remains: why the subjects' trend towards order? In this section, I hypothesize that this trend is a reflection of a similar tendency prevailing in the physical world.

Recall Machlis's explanation of tonality, reproduced once more below:

> *[...] This "loyalty to the tonic" is fostered in us by much of the music that we hear. It is the unifying force in the do-re-mi-fa-sol-la-ti-do scale [...]. Tonality, needless to say, resides in our minds rather than in the tones themselves. (Machlis 1990)*

His statement suggests that we aim for tonality because the music we hear has such feature. That would lead us to the idea that we aim for visual balance because it is a feature of much of the designs we see. In this sense, tonality and balance would not be something that was innate but something that we acquired during our lives. However, that does not explain why the music we hear and the designs we see acquired such features in the first place. Palladio in his *Four Books of Architecture*, provides a suitable explanation for this problem. He says:

> *[...] For three things, according to Vitruvius, ought to be considered in every fabrick, without which no edifice will deserve to be commended; and these are utility or convenience, duration and beauty. [...] Beauty will result from the form and correspondence of the whole, with respect to the several parts, of the parts with regard to each other, and these again to the whole; that the structure may appear an entire and compleat body, wherein each member agrees with the other, and all necessary to compose what you intend to form. [...] It will also be of the utmost advantage to the whole structure, if the walls are equally and expeditionally carried up: for being thus dispatche'd, they settle proportionally, every where alke, and no be subject to those clefts so commonly found in buildings that have been finish at divers times.*

According to his reasoning, a building should be symmetrical because it guarantees that it will not collapse. If we consider that the technology available at the time consisted essentially in load-bearing walls or columns, we have to agree with his argument. If we also consider how influential were Vitrivius' and Palladio's treatises, we can explain the aim for balance in western architecture. We would then say that the aim for balance and symmetry in architecture is due to a tradition transmited to us either directly by education, or indirectly by the buildings we see. However, symmetry is also a feature found in non-western architecture and in western architecture previous to Vitruvius which did not require symmetry to avoid collapse. I am thinking, for instance, about the form of the houses found in

Celtic and Iberian settlements previous to the Roman conquest. The plant of these houses usually had the form of a circle or a square. The fact is even more astonishing if we take into account that those houses were often located on slopes and very irregular sites where the settlements were often located for defense purposes. How can we justify the use of such simple and ordered shapes in such early settlements? I argue that the human tendency towards simplicity, and order, whatever form it takes, has deeper roots that can be traced to the structure of the physical world.

The idea that there is a psychological tendency towards, simplicity and order has already been emphasized several times. *Gestalten* theorists, for instance, showed that the human mind tend to perceive geometrical patterns in such a way that the simplest available form results (Fig. 7.97). Freud, also referred to a tendency observed in human behavior that he described as the principle of the least effort. According to this principle, which I have already mentioned in Section 7.2.11, among several possible ways to achieve a certain goal, people tend to choose the one that consummes less energy.

The idea that the psychological tendency towards order mirrors laws of the physical world is not new. It was introduced by Wolfgang Kohler who, impressed by the gestalt law of simple structure in psychology, traced it to similar phenomena in the physical sciences. Rudolf Arnheim also supported this idea in his essay *Order and Entropy* (Arnheim 1974). Arnheim set up the argument in the following way:

> *To be sure, one might surmise that all perception involves a desire to understand and that the simplest, most orderly structure facilitates understanding. [...] Even so, another explanation imposes itself when one remembers that such elementary perceptual behavior is but a reflection of analogous physiological processes taking place in the brain. If there were independent evidence to make it likely that a similar tendency toward orderly structure exists in these brain processes also, one might want to think of perceptual order as the conscious manifestation of a more universal and indeed physical phenomenon.*

The tendency toward orderliness, and indeed towards logic and balance, indeed have their counter-parts in the physical world. The need for logic has its counter-part in the principle that states that there is no effect without a cause. According to this need, designers do not create a design composed of diverse elements if they do not have reasons for that diversity. Therefore, as we saw in Section 7.18.2, the need for logic also mirrors the principle of the least effort. This principle is present in the physical sciences in the form of different laws. In mechanics, it is embbed in the the law of inertia that states that a body continues at rest or in motion along a straight line unless its is acted upon a force. In optics, it is present in the law that states that a path taken by a ray of light between two fixed points in an arrangement of mirrors, lenses, and so forth, is that which takes least time.

As seen in Section 7.2.18, when logic prevents designers from generating diverse designs, it promotes regularity and so it also promotes orderliness. Orderliness, has its physical counter-part in the tendency observed in systems to organize themselves in the most regular form possible under the conditions to which they are subjected. This regularity is attained because it represents a state of stable equilibrium. This state is one in which the system remains at rest because the opposite forces within the system counterbalance each other. The state of balance also is the one in which the potential energy of the system is minimal, and it is also the one in which the entropy of the system is maximal. The tendency to attain a state of maximum entropy constitutes another principle of physics, and takes the form of a law, for instance, in the second law of thermodynamics that states that heat cannot flow from a cold to a hot object.

Finally, the tendency to attain a state of equilibrium (balance) also is a consequence of the existence of conservation laws in physics. Since the early period of moden physics there have been conservation laws, which state that certain physical

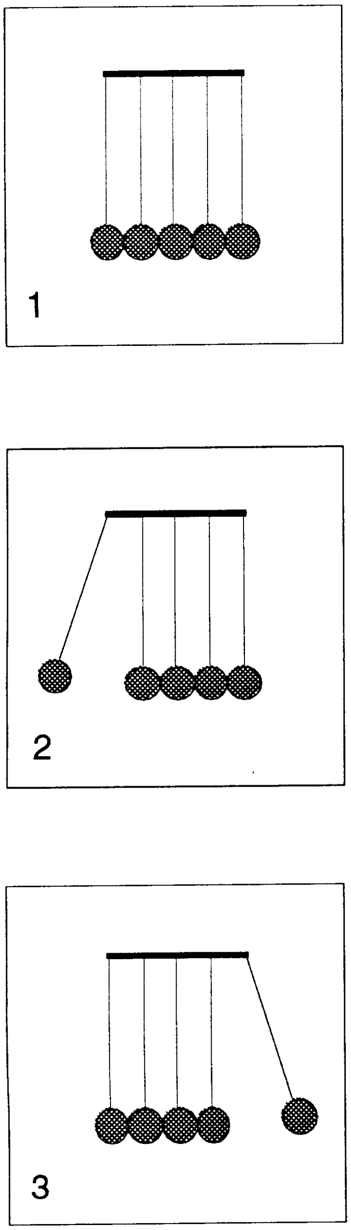


Fig. 7.129
Experiment with pendulums

quantities of an isolated system of bodies do not change in the course of time. Conservation laws are valid in classical, relativistic, and quantum theory for, momentum, angular momentum, mass-energy, and electric charge. For instance the law of conservation of momentum, momentum being equal to the mass of a body multiplied by its velocity, is behind the phenomenon observed when we pull out and release balls in a pendulum formed by several balls (Fig. xx). If we pull out and release one ball on one side, we will see that one of them swings out on the opposite side (a). If we pull and release two, three, or four balls, we will see that an equal number of balls swings out on the other side (b,c and d). This kinetic experiment shows that having the initial equilibrium of the system formed by the several balls been perturbed, the system evolved in such a way as to maintain its integrity and regain its stability. It illustrates, therefore, the principle encoded in all conservation laws that evey action results in an equal and opposite reaction. This phenomenon is especially observed in growing systems. When a new element is added to a system in equilibrium, its state of equilibrium is altered and the elements that compose the system re-arrange themselves in order to attain a new equilibrium.

Note how this behavior is very similar to the one observed in the subjects of our experiments who tried to introduce various elements in order to satisfy the requirement of diversity but at the same time were counterbalancing the visual effect of each element or group of elements with the visual effect of another element or group of elements. Note particularly, how the designs evolved in such a way as to converge to a final state of balance.

The discussion above can be summarized in the following way: because certain physical entities are constant (mass-energy, for instance), the increase or decrease of one of the entities that form it, is accompanied by a proportional decrease or increase of the complementary entity. Thus, the existence of balance. The principle of entropy, the balanced state of a system is also the one in which its energy is minimum, presenting the systems the most possible orderly form under the given conditions. Since the physical world is governed by such principles if perception is the result of physical and chemical operations in the brain, it has necessarily to mirror those principles, and so we can understand our trend towards order in our cognitive activity.

7.2.19.7 Inherent order and perceivable order

How is order perceived?

Logic, orderliness, and balance are different manifestations of the same order only perceived differently

We have to guarantee that each manifestation of order is perceived at an adequate level at the adequate scale

In the previous sections, I referred to three types of order: orderliness, logic order, and balance. In this section, I will emphasize how the three different types of order did not exclude each other but coexisted in the same design. I hold that orderliness, logic order and balance are not, in fact, different types of order but different manifestations of order that are perceived differently. Finally, I hold that although a system may be ordered the perception of all three manifestations of order is necessary to give the observer the sense of order.

Consider, for instance, Wade's design. We saw in Sections 7.2.18.1, 2, and 3 how Wade was concerned with orderliness, logic order,a nd balance, and how his design process mirrored these concerns. Therefore, Wade's design shows that the three types of order can coexist in the same design. This fact is also a feature of all the other experimental designs, as one can confirm in the discussions in Sections 7.2.18.1,2 and 3. What is the explanation? There are two explanations that are related.

First, I argue that logic, orderliness, and balance are not, in fact, different types of order but different manifestations of the same order that are perceived differently. Recall, our description of the experiment with the five pendulums. We pulled and released the first ball on one side causing the last ball to swing out on the other side (logic). Because the last ball was identical to the first (orderliness), the system formed by the balls was able to attain a state of equilibrium (balance). Can then be assured that if a system is in balance it is perceived as ordered? If the system is in balance it guarantees, in fact, that it is also orderly, at least to some degree. However, the fact that the system is in balance does not not guarantee that an observer will be able to perceive its balance and its orderliness. In fact, there is a difference between the inherent order of a system, and the order that the observer is able to perceive with his senses, as shown in discussion on scale.

If logic, orderliness, and balance, are different manifestations of the same order, their coexistence in the same design, therefore, the perception of only one manifestation of order is not enough to give the observer the sense of order. In other words, the designer must perceive the coexistence of these manifestations. In fact, it is possible to show how the subjects of the experiments were concerned with each manifestation of order. Some moves were prompted because they did not perceive enough orderliness, others because they did not perceive balance, and finally others, because they did not perceive a logical generation of the design. Taylor, for instance, corrected the flaws of Wade's design in terms of balance, and designed an orderly vertical glazed tower because he saw no justification for the random cluster of windows in Wade's design.

We can conclude that if we want to guarantee that a system, such as a row of houses, is perceived as ordered, we have to guarantee that each of the three manifestations of order are perceivable in an adequate degree at the selected scale. We should then, take this into account in the development of a computer program that generates housing facades, like the one presented at the end of this thesis.

8. Conclusions

In the first part of this thesis, we saw that although diversity in design was a goal of systems concerned with the mass-production of housing, their use generated monotonous and repetitive street environments. We then did two experiments with the goal of discovering why designers seem unable to use modular systems to generate diversity, how diversity is perceived and whether that information could be encoded into the computer to be used as a tool to overcome this flaw.

Results confirmed that despite some limitations, a small set of elements can generate more diversity than designers' were able to attain. In fact, the designers in the experiment neither considered their designs diverse, nor used all the elements and colors available. In addition, the total of the designs was more diverse than each design. The factors behind such flaws are summarized below.

8.1 Factors that Limit Diversity in Designing

The experiments identified three different types of factors that constrain designers ability to generate diverse designs using a modular system. The first are limitations of the system, the second are limitations of designers, and the third are factors external to both the system and designers. These factors, as well as the relationships among them, are diagrammed in Fig. 8.1, and briefly described below.

a) System's limitations

1. Mismatch of design worlds: The system fails to provide elements and rules of a design world that correspond to designers' own design worlds.

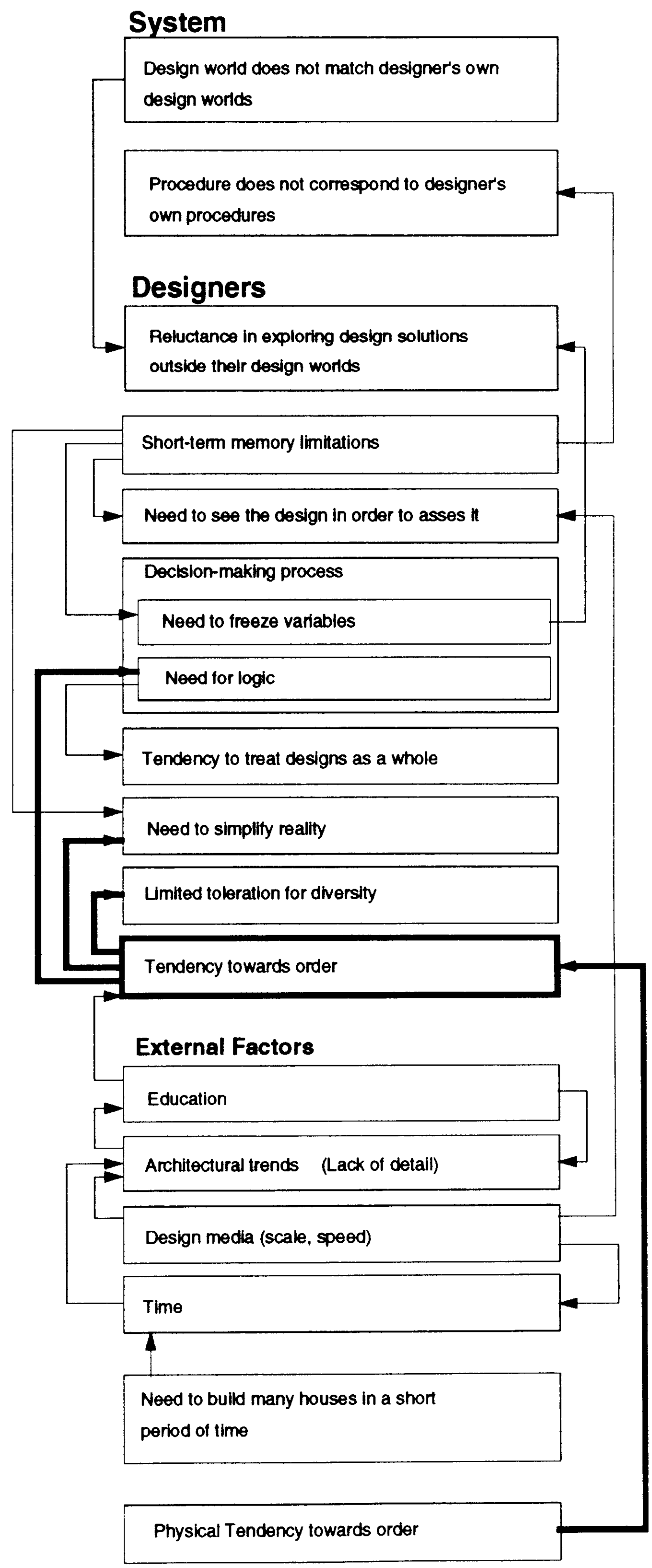


Fig. 8.1
Factors that limit diversity in designing

2. Mismatch of procedures: The system's rational procedure does not match designer's own procedures, which is driven by memory and appraisal constraints. The need to follow a rational procedure becomes an important requirement constraining the design process, already over-loaded with the amount of data required to create diversity.

b) Designers' limitations

1. The reluctance to explore design solutions outside their own design worlds: Despite the requirement of diversity designers do not consider the use of elements or solutions provided by the system that they do not like. Since different designers select and reject different elements and create different rules, a street that is designed by the one designer is likely less diverse than one designed by several designers.

2. Short-term memory limitations: Prevent designers from manipulating more than a certain amount of data at a time.

3. The need to see their designs in order to appraise them: Due to short-term memory constraints designers need to see a design solution in order to appraise it. The more diverse the design is, the less the designer is able to asses it without seeing it. Therefore, the possibility of designing a diverse design is limited.

4. The decision-making process: Due to short-term memory limitations, the decision-making process is characterized by the constant need to freeze variables. On another hand, it also has a principle of logic according to which decisions cannot be made randomly. Since designers are not able to remember small design requirements and do not make decisions randomly, they are prevented from generating diversity.

5. The tendency to treat the design as whole: It is related to their need for logic that leads designers to subordinate the entire design to the same generative logical process. Because designers tend to formally subordinate the functional parts of their design to that of the whole, there is no clear correspondence between formal and functional wholes in their designs. Because of this lack of identity, the designs are not perceived as being composed of distinct elements, and therefore they are perceived as less diverse than could be.

6. The tendency to simplify reality: Due to memory constraints and their sense of order, designers abstract from reality what they consider its essential features, and so they tend to neglect minor design requirements that could increase the diversity of their designs.

7. A limited toleration for diversity: Due to either their sense of order or to their education designers do not tolerate more than a certain number of diverse elements within a certain area. The result is a tendency to restrict diversity at the design scale. Due to the effect of scale on the perception of diversity, their designs tend to look more diverse than the architectural artifacts they represent.

8. Psychological and aesthetical tendencies towards order: Likely a reflection of a similar tendency existing in the physical world and strenghen by education, such tendencies take three forms: the need to see a logical generation of the form in their designs, the tendency to generate the most possible orderly arrangement of elements, and in such a way that equilibrium results.

c) External limitations are:

1. Design media: current media prevents designers from effectively assessing how factors that affect the perception of

diversity influence their designs, such as scale, motion or three dimensions. Facades tend so to look less diverse, to be repetitive, and flat. Because current design media are slow, they do not allow the designer to generate and test easily various design posibilities. This flaw becomes especially important in a diverse design in which the attributes of its elements take various values, thus requiring the generation of various design possibilities in order to test the effect the various values on the design.

2. Architectural and non-architectural education: This reinforces the tendency towards order and disseminates architectural trends that encourage the lack of architectural detail required for the perception of diversity beyond a certain scale.

3. Time: Its scarcity limits designers ability to generate numerous design solutions which prevents them from seeing how diverse attributes affect the design.

8.2 Factors affecting the perception of diversity

The experiments indentified some factors that influence the perception of diversity:

1. Short-term memory: Designers have limited short-term memory. This feature affects their ability to remember features of architectural artifacts. Consequently, too much diversity prevents them from perceiving repetition which prevents designers from perceiving order.

2. Opportunity, conflict, and ambiguity: The exploration of unexpected features of the design at a given moment of the design process has the potential to generate rules that conflict with previous ones. The existence of conflicting rules creates ambiguous designs which allow multiple ways of perceiving the

design, and so it contributes to an enhanced perception of diversity.

3. Correspondence between functional and formal parts and wholes: Designers have a tendency to treat their designs as a whole. Because of this tendency they formally subordinate the funtional parts of their design to that of the whole, and so there is not a clear correspondence between formal and functional parts and wholes. Because of this lack of identity, the designs are not perceived as being composed of distinct elements, and so they are not perceived as diverse as they could be.

4. Scale, and distance: The influence of scale and distance on the perception of diversity are very similar. A very small scale, or a large distance from a given object to a given observer affects his or her ability to perceive distinct elements and so the object is perceived as less diverse. A short distance or a large scale causes the observer to see only part of the object, and so the object might be perceived as less or more diverse than it is depending on the repetition of its parts.

5. Three dimensions: Since each view of a three dimensional object is unique, objects that have three dimensions are perceived as more diverse than two dimensional ones. Moreover, the more three dimensionally diverse an objects is, the greater number of different views it allows, and so is perceived as more diverse.

5. Repetition and surprise: The perception of repetition leads to the establishment of rules, and so an unexpected variation is perceived as an element of diversity, whereas a constant variation might become either predictable or chaotic.

8. 3 Perception of order

The experimental results showed that the perception of order in a design is an important requirement, and identified three different manifestations of order: orderliness, logic order, and diversity.

1. Orderliness: Orderliness describes the features of an arrangement of elements emphasizing repetition, whereas diversity emphasizes variation. Repetition and variation are different ways of looking at the same aspect of the arrangement of elements called variation-repetition. Orderliness is, thus, related to diversity through repetition, and so it is referred to as orderliness-diversity. Based on this relatioship, an algorithm for orderliness-diversity is proposed.

2. Logic order: Logic order is the result of designers' need to tie the development of the design to some logical generative rule and is a required feature for an observer to perceive an architectural artifact as ordered. By tying the entire design to the same logical generative rule, logic order constrains diversity and promotes orderliness .

3. Balance: Two different types of balance are identified: horizontal and vertical balance. The perception of horizontal balance is compared to the way we listen to tonal music whereas vertical balance is related to the visual weight of the elements in the design. Based on these metaphors and on the way the design process of the experimental subjects evolved, an algorithm for each type of balance is proposed.

The perception of vertical balance is closer to the way we look at a building from a static position. The perception of horizontal balance is closer to the way we see one building after another as we move along a street. The facade of one building should be in vertical balance, whereas a street facade should be in horizontal balance

The perception of the three manifestations of order is necessary to perceive an arrangement of elements as ordered. Since scale and other factors affect the perception of order, there is a difference between inherent and perceivable order. Therefore, in order to perceive a street facade as ordered the three manifestations of order have to be perceived in an adequate degree at the right scale.

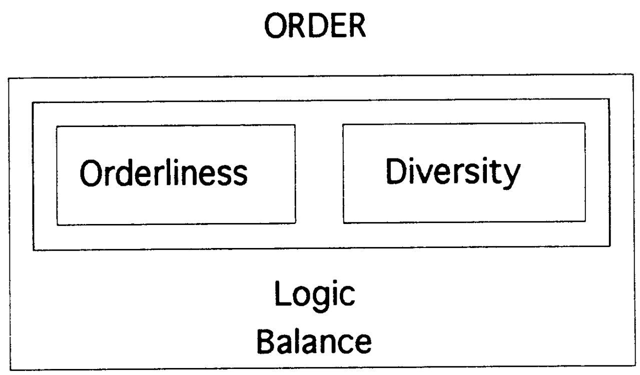


Fig. 8.2
The relationship between the different manifestations of order

8.4 Formal solution for a diverse street facade

Because a high identity between formal and functional parts enhances the perception of diversity, a row of houses is more diverse than a large cluster of dwellings.

8.5 Design Rules

Prescriptive rules permit the achievement of a better diversity than proscriptive rules.

Among possible design solutions, designers pick the one that satisfies more design requirements.

9. The Street Facade Generator

Based on the experimental results summarized in the previous section, this section introduces a methodology to overcome designers' limitations to generate diverse facades within a modular system. It uses a shape grammar as a generative set of rules, the three algorithms developed as evaluation rules, and the computer as the design tool. The specific program developed is called the Street Facade Generator.

9.1 The shape grammar (and the color grammar)

Before describing the specific shape grammar developed I will briefly explain what a shape grammar is and why it can be used as a partial solution to generate diverse designs within a modular system.

9.1.1 What is a shape grammar?

The concept of a shape grammar was first introduced by Stiny (1975) who developed a pictorial shape grammar and then further developed by Stiny and Mitchell (1980) who developed a grammar for palladian villas. Since then other authors have developed other grammars such as a one for Frank Lloyd Wright's prarie houses (Koning, Eizenberg 1981), and another for Queen Anne houses (Flemming 1987).

A shape grammar is defined by a vocabulary of shapes—the shape primitives, by a set of transformation rules that apply to those shapes in a recursive manner, and by labels or markers that identify the shapes to which a specific rule can be applied. Fig. 9.1 illustrates one rule and a design generated by that rule in one of the pictorial shape grammars developed by Stiny.

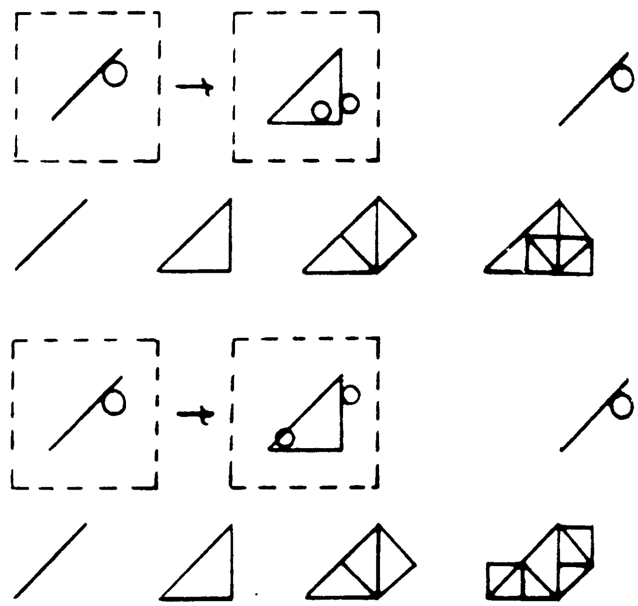


Fig. 9.1
Pictorial shape grammar (Stiny, 1975)

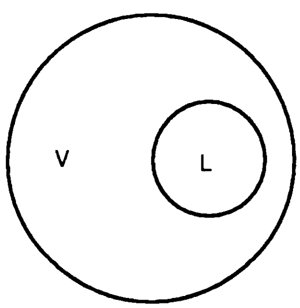


Fig. 9.2
The universe of designs L defined by a grammar is a subset of the universe of designs V defined by all the design operators from the shape primitives

The universe of designs defined by a grammar (Fig.9.2) is a subset of all the possible combinations of shapes that can be obtained from the shape primitives using either shape tansformation operators such as rotation and scale (Fig. 9.3-1), or shape combination operators such as subtraction and addition (Fig. 9.3-2). A grammar restricts, thus, the universe of designs. For instance, all the designs in Fig. 9.4 are in the universe of designs defined from the same initial shape. However, the grammar defined by each rule is a different subset of all the designs that can be obtained from the initial shape. The ability to restrict the design world is one of the most important features of a shape grammar because it can be used to eliminate designs that for some reason are considered as not suitable.

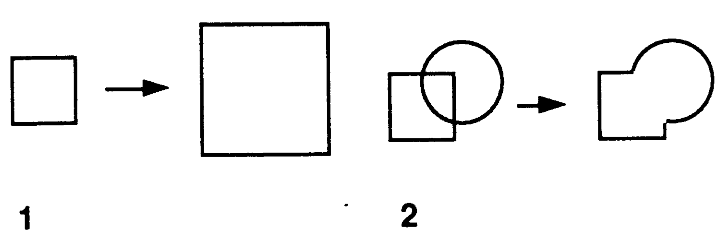


Fig. 9.3
Operators. Example of a transformation operator—scale (top), and example of a combination operator—addition (bottom)

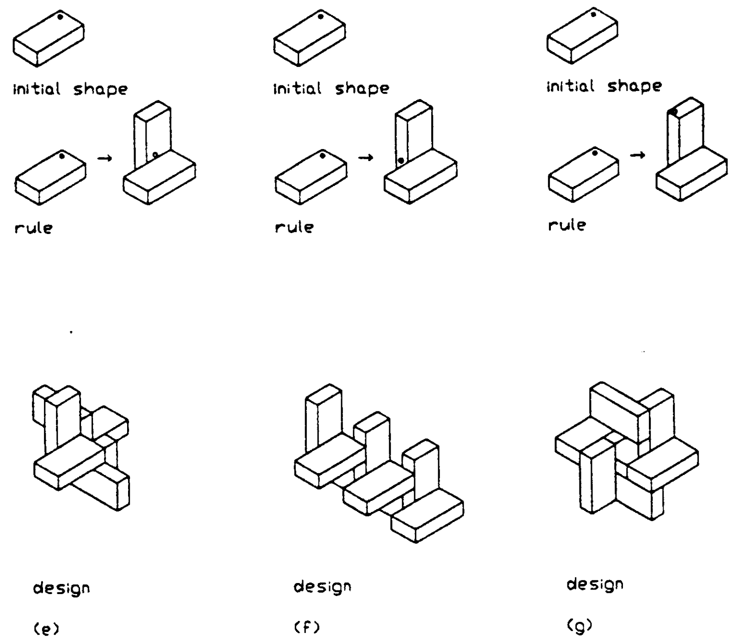


Fig. 9.4
Grammar rules and designs generated by those rules

9.1.2 Why a shape grammar?

Some of the advantages in using shape grammars to generate diverse designs are due to features of shape grammars themselves, whereas others only come about by using them in association with computers. Both the use of shape grammars alone, and their combined use with the computer, overcome many of the difficulties in the generation of diversity caused by the factors outlined in Section 8.

1. A shape grammar can encode the rules of a modular system: In order to define a shape grammar one needs to define the shape primitives and the rules. If we consider the system's modules as the shape primitives, its rules can be defined in the form of shape grammar rules. Fig. 9.5 illustrates such rules for the structural elements of the specific system presented in Section 2.1 and used in the experiments.

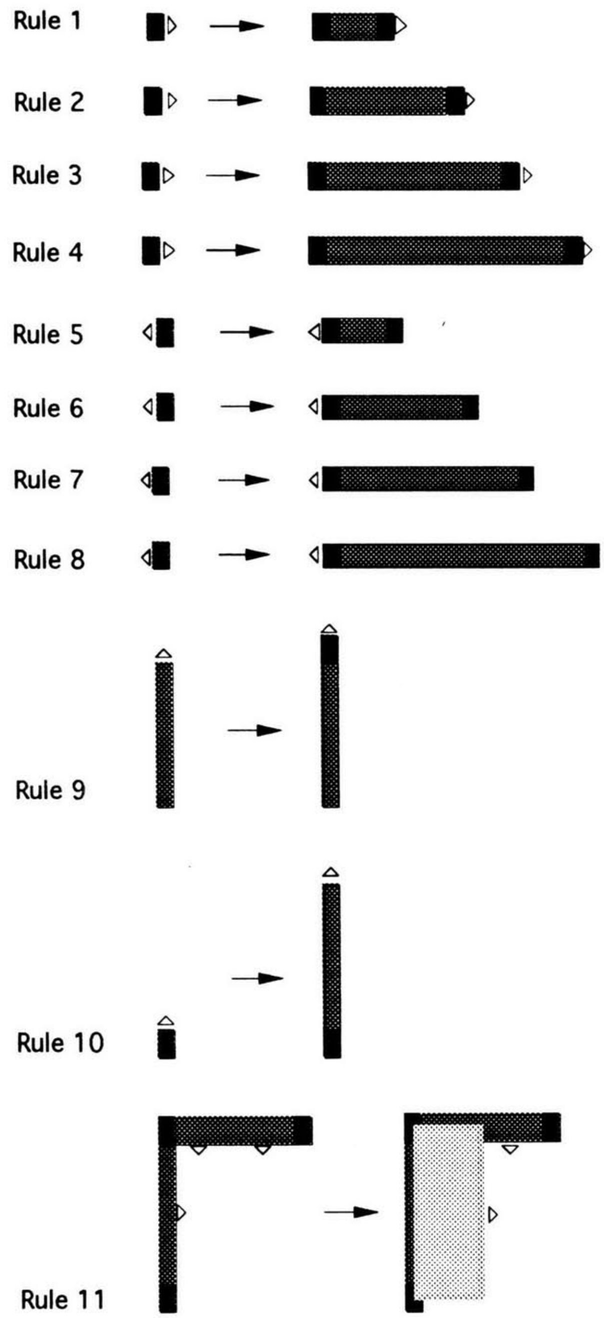


Fig. 9.5
Shape grammar rules for the combination of the structural elements of the system presented in Section 2.1 and used in the experiments

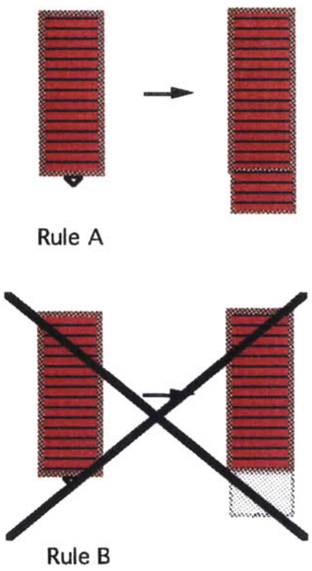


Fig. 9.6
Rule used by Ana in her design process (A) and rule that she did not use

2. A shape grammar can encode the rules defined by a designer within the modular system: Such definition implies a restiction of possible solutions, either by suppressing some of its rules, or by developing additional rules. Fig. 9.6 illustrates a shape grammar cladding rule used by Ana in her design process, as well as a rule that although being a system's rule she did not use. Such restriction was a consequence of her rule *the facades should be of only one color (Verbal Protocol; rule 4 ,Appendix B.6).*

3. Use of the computer: A shape grammar codifies some architectural knowledge in such a way that enables the use of the computer to generate designs. By enabling such use, a shape grammar introduces a methodology that overcomes the mismatch between the system's and the designers' design procedures. In fact, since the system's procedure is encoded into the computer in the form of shape grammar rules, the designer does not have to follow himself the system's procedure. The combined use of the computer also overcomes other limitations in the generation of diversity, described below.

4. Manipulation of data: By using of the computer, a shape grammar facilitates the manipulation of large amounts of data and complex relationships, thereby overcoming designer's short-term memory limitations and the resulting need to simplify designs.

5. Appraisal: By enabling the use of the computer a shape gramar permits to rapidly generate and test different design possibilities, thereby satisfying designer's need for appraisal, and overcoming time constraints. Therefore, it allows testing of the impact of various attribute values on the overall design, facilitating the generation of diverse designs.

6. User participation: By facilitating appraisal it allows user participation in the design process, which generates

customized diversity. It gives, therefore, some power of decision to the users, pressing the designer to overcome his reluctance in exploring design solutions outside his own design world, his limited toleration for diversity, and his tendency to treat designs as a whole.

7. Decision-making process: We saw that the decision-making process is characterized by the need to freeze variables and the need for logic. By freezing some variables and varying others a shape grammar follows to some extent the way a designer makes decisions allowing him to test the impact of variations of specific attribute values on the design. By enabling the generation of a customized diversity it satisfies designer's need for logic in the generation of diversity.

8. Logic: By generating designs according to the same set of rules, a shape grammar guarantees some satisfaction of the need for logic in the perception of order.

9. Orderliness: By encoding rules that constrain the rules of the modular system and by generating designs in the same grammar, a shape grammar guarantees a certain level of orderliness.

10. Diversity: In the discussion in Section 7.2.15 we explained that due to a one-to-one mapping between functional and formal parts, a row of houses is potentially more diverse than a large cluster of dwellings. A shape grammar can be developed to generate diverse houses. Examples of such grammars have already been developed both by Koning and Eizenberg (1981) for Frank Lloyd Wright's prairie houses, and by Flemming (1986) for Queen Anne houses. The second example is especially interesting since it encodes not the rules behind a set of houses designed by the same architect, but the common rules behind a set of houses designed by several designers during a certain period of time and characterized by their diversity:

(...)It rejected the traditional concept of unity and design, deliberately contrasting shapes, textures and color—solid and void, in and out, square and round, light and dark, rough and smooth. ***Paradoxically, this busy allover pattern created a unity of its own, very much like a patchwork quilt that makes a strong design out of many different fabrics. (Maas,*** *1972, quoted in Flemming 1986)*

Therefore, by having the ability to generate various housing facades, a shape grammar satisfies the need for diversity.

11. Scale: Since a shape grammar applies recursively rules at different scales, it satisfies the need for the perception of diversity at different scales. It allows to replace detail in architectural design. The structure of designs can come closer again to the factal structure of nature (Fig. 9.7).

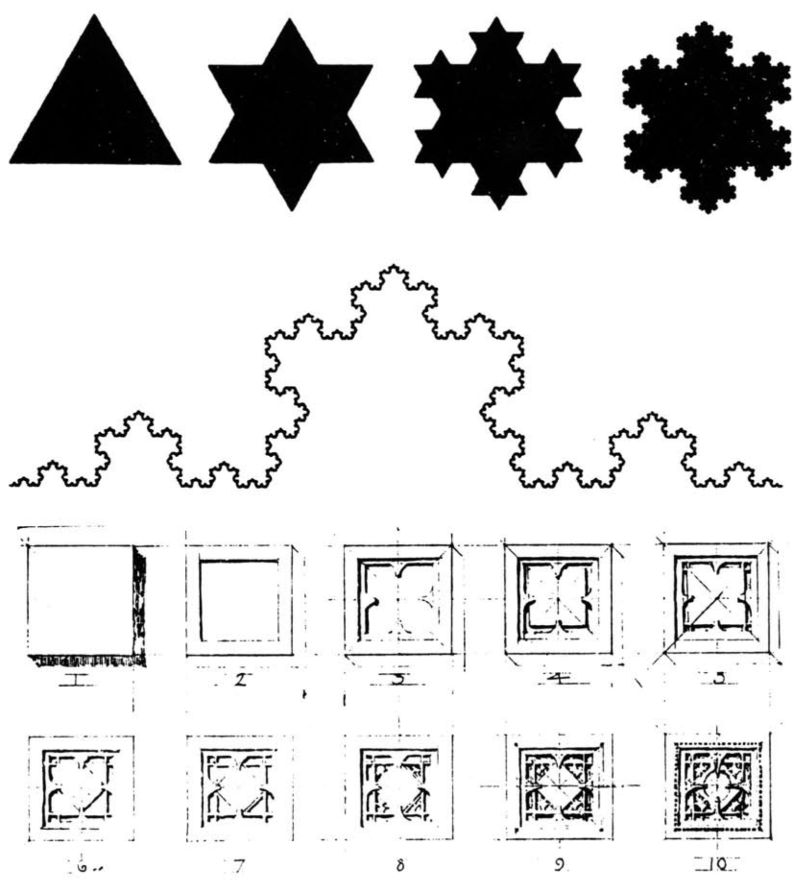


Fig. 9.7
Parallel between a fractal and a shape grammar

9.1.2 A shape grammar as a generative tool

The goal of a shape grammar has essentially been to make explicit the set of rules underlying a designer's style. It has thus been used as an analytical tool. Nevertheless, I believe that the most challenging use of a shape grammar is the possibility of using it as a generative tool. This is, at least, the point of view taken in this thesis, due to our goal of using a shape grammar to overcome limitations in diversity. There are, however, some problems with such use. Analytical grammars are developed after a careful process of analysis which assumes the existence of a fair number of designs which are used as analytical samples to infer the rules. Nevertheless, if we want to develop a grammar to generate new designs, we do not have such possibility.

So, if one wants to develop such a grammar, the process might require one to go through a process of diving into his own mind. However, self-examination might be a difficult thing to do. As Minsky expresses it:

> How much genuine self-insight is possible for us? I am sure our memory-machinery provides some useful clues, if only we could learn to interpret them. But it is unlikely that any part of the mind can ever obtain complete descriptions of what happen in the other parts, because, it seems, our memory-control systems have too little temporary memory even to represent their 'own' activities in much detail. (Minsky, 1988)

In addition, the development of such grammar assumes that one has already intuitively developed a grammar in his design activity. However, design is a learning process. It is by designing that a designer develops his architectural language. If we have not yet designed how could have we developed such grammar?

We have, therefore, to find another way of defining such grammar. Such a way could be to ask other designers to design for us, and then analyze his or her designs in order to infer the rules, thereby avoiding the need for self-examination. If the designer whom we ask to design for us is a mature designer, we will also overcome the second problem. I am thus proposing the use of an experimental setting similar to the one used in this thesis as a methodology to develop a grammar to generate new designs. I illustrate in the following section how such methodology leads to the development of a shape grammar.

9.1.3 The specific shape grammar developed

The specific shape grammar developed was based on Ana's design, one of the subjects in the *Spoken Game with Architectural Elements*. The shape grammar encodes, thus, both the basic rules of the system, and the rules developed by Ana within the system. There are two main reasons behind the selection of Ana's design, despite the fact that she was not a designer. The first, is the fact that she was the only subject who created a row of houses, thereby creating a design with a high degree of identity between functional and formal wholes, so important in the perception of diversity as pointed out in Section 7.2.15. The second is the fact that she also was the subject who achieved a suitable balance between orderliness and diversity, as pointed out in Section. 7.2.19.1.

The shape grammar defined has three main features: first, although it was based on Ana's design, it defines a larger universe of designs; second, it is defined in a bottom-up fashion; and third, it is organized in levels, and has associated a color grammar.

a) enlargement of the universe of designs

If we have strictly followed the rules defined by Ana in her design (listed in Appendix B.6), we would have created a shape grammar with a very limited ability to generate diverse designs. In fact, the universe defined by her rules is not very large. For instance, the number of different configurations for the superstructure (Section 7.2.19.1) is only four due to the combined effect of the rules:

> *The doors should not be at the ground level* (Rule 6),
> *All the houses have a cornice* (Rule 21),
> *All the houses have a roof (Rule 22),.*
>
> *(Ana's Verbal Protocol)*

It is also limited by the fact that she used only one height for the grounding panel used to raise the door level above the street, and that she either built a five or a six panel long houses (2 x 2 =4). Considering the different colors that could be used for the walls (3), the cornice (1), and the grounding (1), the number of different configurations for the superstructure would be 3 x 4 = 12, still very low. Although, the consideration of the number of different windows and doors, and their corresponding details raise considerably the number of different houses, the fact remains that only twelve different configurations constitute an important limit for diversity. Such limitation would not even make worth the effort spent in the development of such the shape grammar.

The limitations imposed by Ana's rules are a consequence of the decision-making process behind the development of her prototype, as pointed out in Section 7.2.11. We have, therefore, decided to enlarge the universe of designs of the shape grammar by breaking some of her rules. Notice, that Ana also used such procedure in her design process, when she realized that her rules were becoming too restrictive. For instance, when she realized that a street with houses with five panels long—the length of the protypical solution, would not be enough diverse, she designed a house six panels long, although that solution was not so perfect from her rules viewpoint.

We enlarged the grammar in a two step process. First, we considered that her houses could not have a grounding, a cornice or a pitch roof. The number of possible design solutions for the super-structure reached then 2 x 2 x 2 x 1 x 2 = 16, without the consideration of wall color and wall width variations, 16 x 2 = 32 with the consideration of the two wall widths that she used, and 32 x 3 = 96, with the consideration of the three wall colors available. Second, we admitted that both the grounding, and the cornice could also have parametric variations in terms of height, being the parametric values (attribute values) considered the ones shown in Fig. 7. 99. We also enlarged the number of possible values for the wall width up to seven, and down to three. The number of possible design solutions for the superstructure reached then (2 x 5 x 2 x 1 x 4) x 5 x 3 = 1,200. If we considered that the grounding, the floor walls and the cornice could have different colors, we would enlarge the universe of solutions up to 10,800. However, we did not do so because we considered that 1200 different solutions for the superstructure were enough to illustrate the possibility of using a shape grammar to generate diverse houses. By considering that the design could have parametric variations we transformed the developed grammar into a parametric shape grammar.

b) Bottom-up process

Considering Ana's prototypical solution, we could either develop the grammar in top-down or bottom-up fashions (Fig. 9.8). We used a bottom-up process, since it has the advantage of following the modular nature of the system, originating some advantages in programming, such as the use a unique symbol for each module. In fact, the use of symbols avoids the need to redraw a module each time it is used, and so, it saves computer memory and speeds up the generation of designs. Additionally, since Ana also designed in a bottom-up fashion due to the experimental setting, the use of such a process in the definition

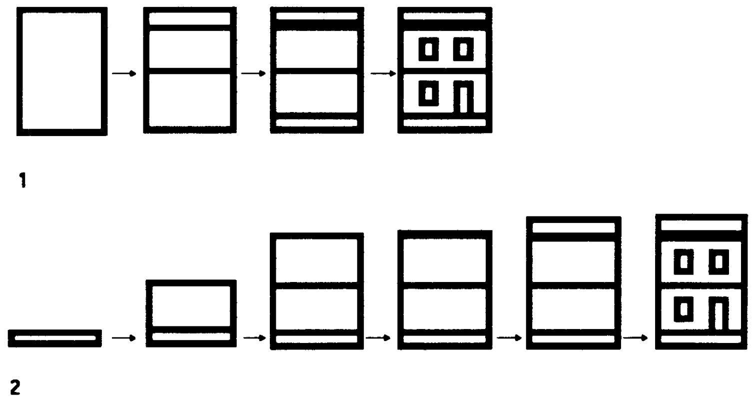


Fig. 9.8
Top-down (1), and bottom-up grammars (2)

of the shape grammar allows a close parallelism between her operations and the shape grammar rules.

c) The use of levels

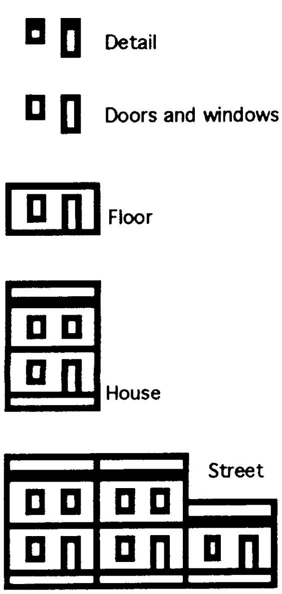


Fig. 9.9
The levels of Ana's design

The shape grammar is organized in levels. Such organization is due to a similar organization existing in the conception of the system as described in Section 2.1, but also to the fact that it is also implicit in Ana's design process as shown in Fig. 7.42. Recall, how she built her street, by performing a sequence of operations. The levels of her design are diagrammed in Fig. 9.9. Each shape grammar rule encodes one of these operations. The basic rules of the developed grammar are the panel placing rules being the initial shape a wall panel. We decided to neglect the structural rules because our main concern was to illustrate how a shape grammar could be used to generate diverse facades. The panel placement rules are illustrated in Fig. 9.10. There are three different types of such rules: one to introduce an initial shape, one to introduce another panel, and another to delete the rule marker (termination rule). The basic difference between the various rules to introduce another panel is whether or not the placed panel has the possibility of having a door or a window. We decided not to

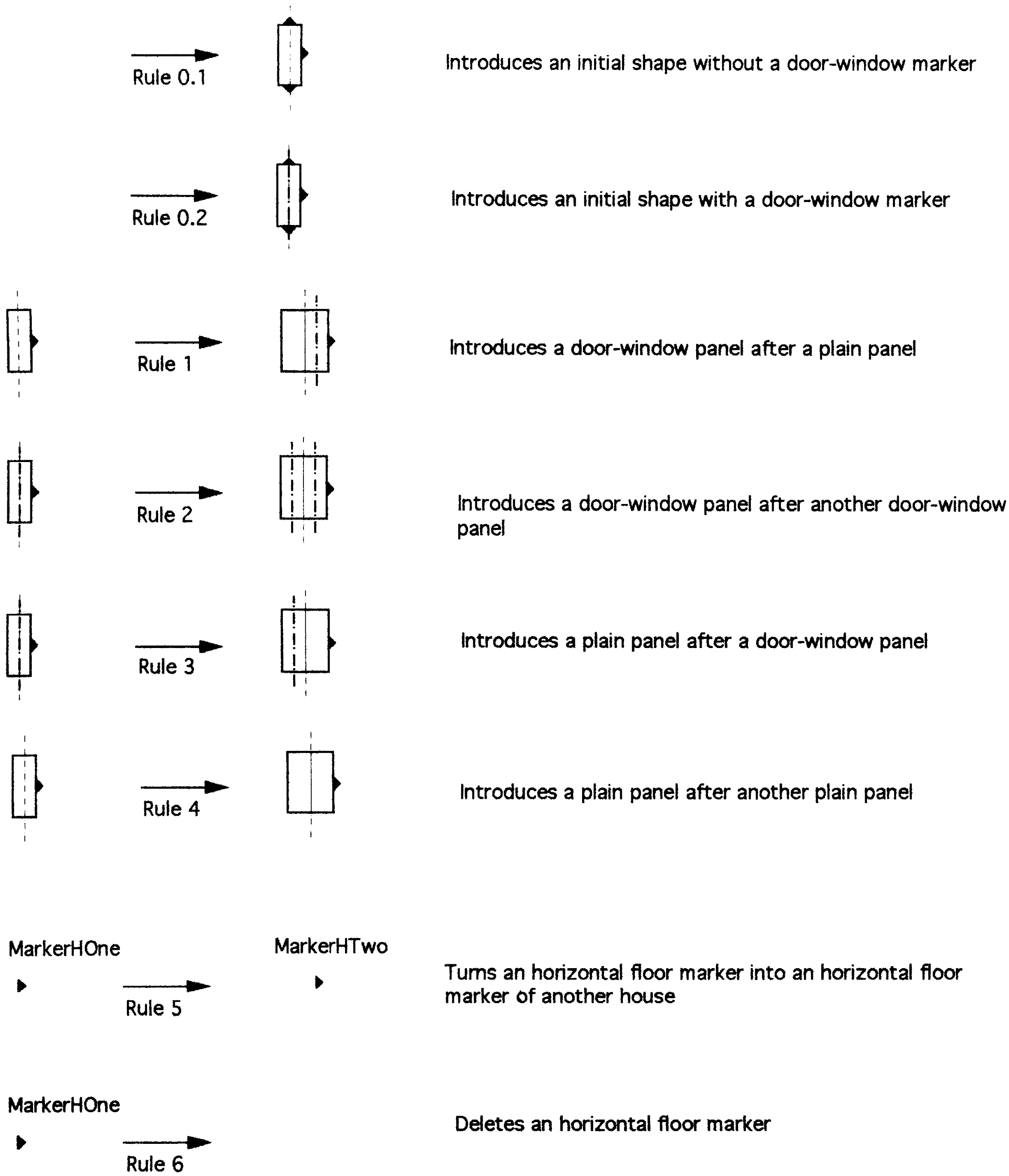
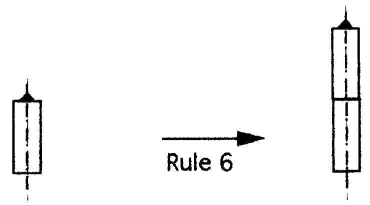
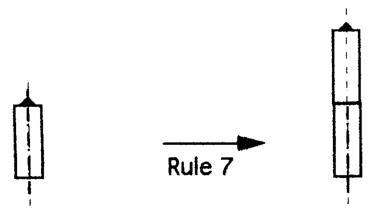


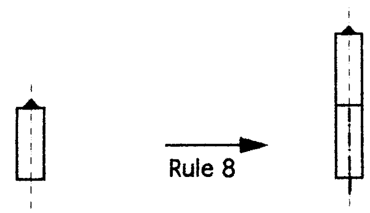
Fig. 9.10 (continued)
Ana's design shape grammar
Cladding rules



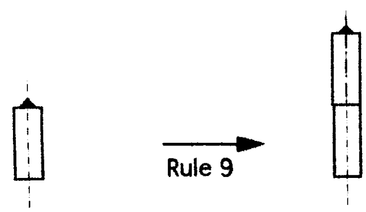
Introduces a door-window panel on the top of another door-window panel



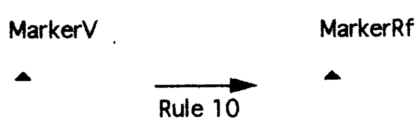
Introduces a plain panel on the top of a door-window panel



Introduces a plain panel on the top of another plain panel



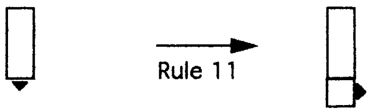
Introduces a door-window panel on the top of a plain panel



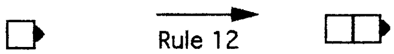
Turns a floor marker into a roof marker

Fig. 9.10 (continued)
Ana's design shape grammar
Cladding rules

Grounding Rules



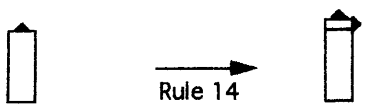
Introduces a grounding panel below a wall panel



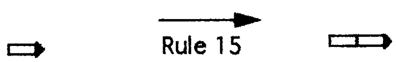
Introduces a grounding panel after another grounding panel

Deletes grounding merker (grounding termination rule)

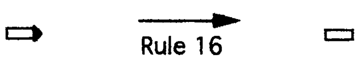
Cornice (or platband) rules



Introduces a cornice (or platband) panel on the top of wall panel



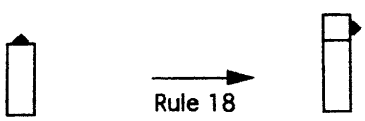
Introduces a cornice (or platband)panel after another cornice (or platband) panel



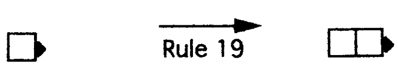
Deletes cornice (or platband) markerCornice (or platband) termination rule

Roofing rules

Introduces a roof panel on the top of a cornice (or platband panel)



Introduces a roof panel on the top of a wall panel



Introduces a roof panel after another roof panel

Deletes roof marker (roof termination rule)

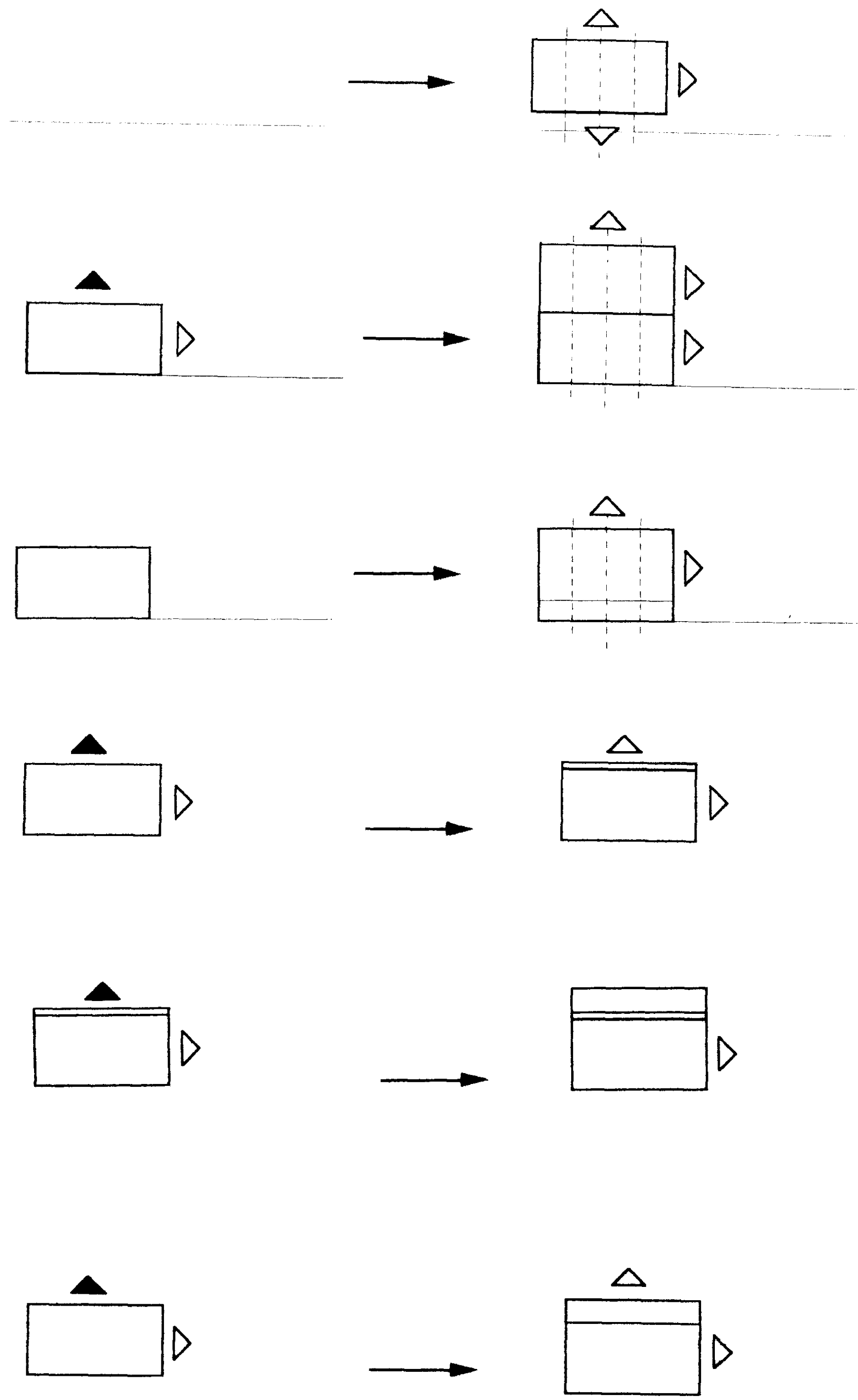


Fig. 9.11
Ana's design shape grammar
House level rules

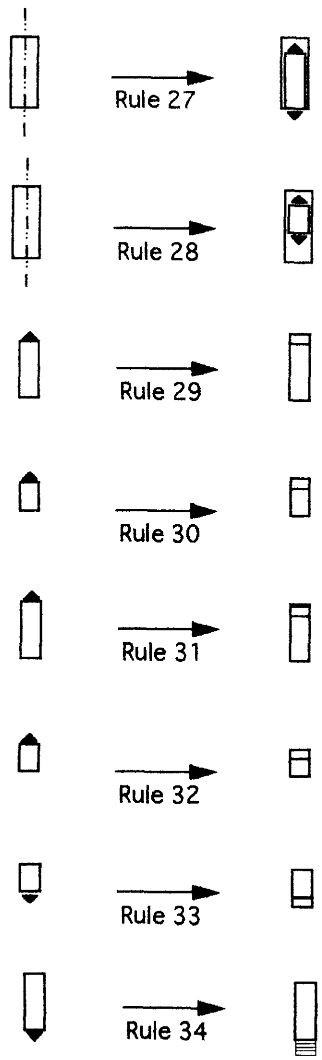


Fig. 9.12
Ana's design shape grammar window and door placement and detailling rules

respect all of Ana's panel placing rules. For instance, we did not respect the rule *the windows cannot be attached to the door* (Rule 10, Appendix B.6), but we maintained the rule *both the windows and the door cannot be placed on the side panels of a house* (Rule 11, Appendix B.6). The reason behind the neglecting of some of her rules was, once again, the need to enlarge the universe of solutions.

The panel placement rules are then organized into rules of another level. These rules include the rules to design the grounding, the floors, the cornice, and the roof, and are illustrated in Fig. 9.11.

The subsequent rules are the rules to introduce the door, and the windows. Finally, the last rules are the ones to detail and expand the door and the windows, according to set of possible solutions shown in Fig. 7.99 (Section 7.2.19.1) . Some of these rules are shown in Fig. 9.12. Although, the universe of solutions is considerable, we considered only two rules in the development of the computer program merely because of time constraints.

d) color grammar

Since color is used, a shape grammar is not enough to encode Ana's rules. For instance, the rule *in the same facade I am not going to paint the windows with different colors* , cannot be encoded by shape grammar rules. Therefore, a color grammar was also developed. Fig. 9.13 illustrates the rules of such a grammar for the superstructure color. As mentioned above, we did not consider the use of rules to have floors, grounding, and cornice with different colors. Although we did not represent graphically color rules for the door and the windows, we also used such rules. In these rules we did not entirely respect Ana's rule *the doors and windows of each house should be of the*

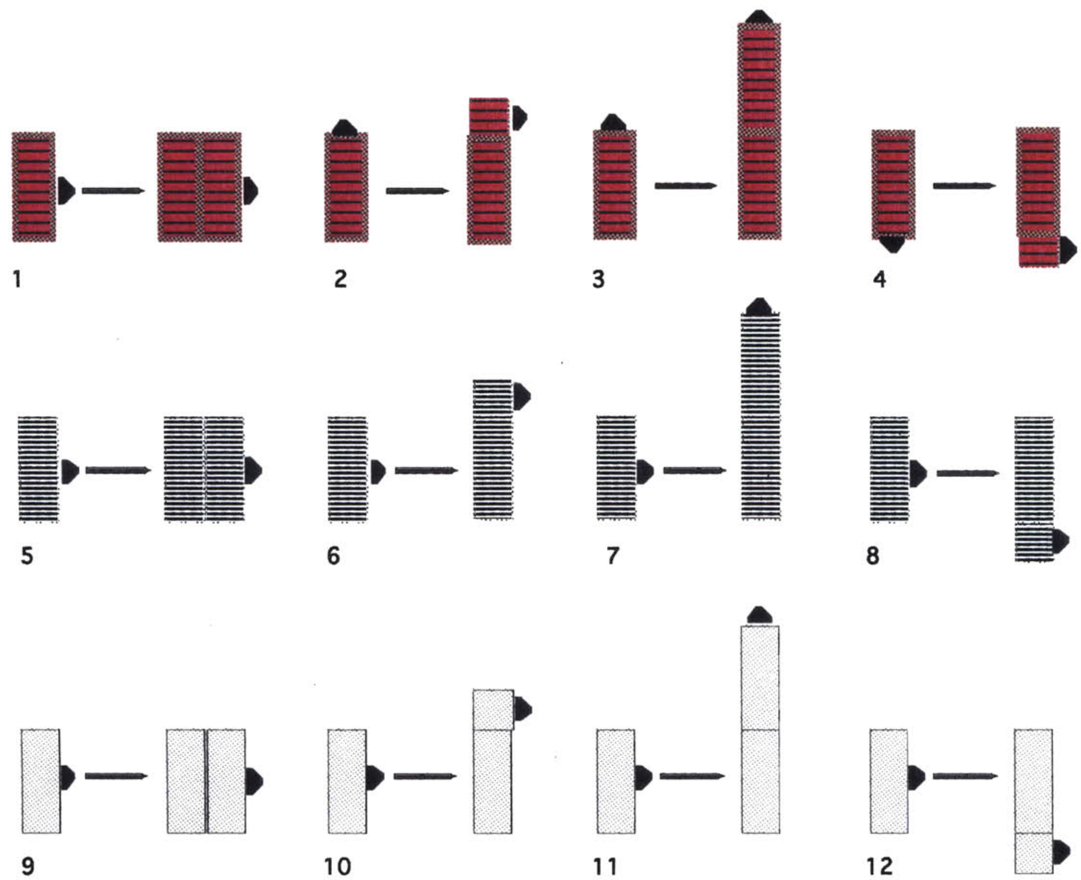


Fig. 9.13
Ana's design color grammar rules

same color. In fact, although we considered that all the windows should have different colors, we considered that the door could have a different color from the window.

In conclusion, although the developed grammar was based on Ana's design, we broke up some of her rules in order to enlarge the universe of design solutions. And we did so by considering parametric variations, thus developing a parametric shape grammar. The developed grammar is organized in a bottom-up process, and into levels. The shape grammar is also complemented by a color grammar. We will describe in the folowing section the computer program developed to support the shape and the color grammars.

9.2 The computer program

The computer program developed to support the shape grammar aims at illustrating how a shape grammar could be used to overcome limitations in the generation of diversity. It is written in MiniPascal, the programming language embedded in MiniCad, the CAD program used in the experiments. MiniPascal is a variation of the Pascal language adapted to suit specific requirements of MiniCad, and so, it is a procedural language like its father program. The reasons for selecting of MiniPascal was threefold. First, it was due to the fact that by being embedded in the CAD program it simplified programming. Second, it was due to its simplicity as a procedural languange in learning and writing programs. And third, it was due to the parallel that is possible to establish between shape grammar rules and programming procedures, which also facilitates programming. The program is, thus, organized into procedures. The use of such an organization strategy allows the development and implementation of the computer program by modules, making easy to expand it or to adapt it to a new framework. In conclusion, the simplicity achieved by using MiniPascal suited the illustrative nature of this study[1].

The program consists of two mechanisms: the Decision, and the Design Mechanism, that interact with each other as diagrammed in. Fig. 9.14, and as explained in following. The program enters the design mechanism (1), but it calls immediately the Decision Mechanism (2), in which the attributes of each house are selected. The program then returns to the Design Mechanism (3) and builds the first house. Then, it calls again the

[1] I believe, nevertheless, that an object-oriented programming language is more suitable for writing a program that manipulates a modular system because the direct correspondence that is possible to establish between the system's modules and the language's objects. Thus, I believe that an object oriented-programming language should be used in an elaborate implementation of programs for manipulating modular systems

Decision Mechanism (4) in order to be define the next house. This procedure is repeated until all the houses are built.

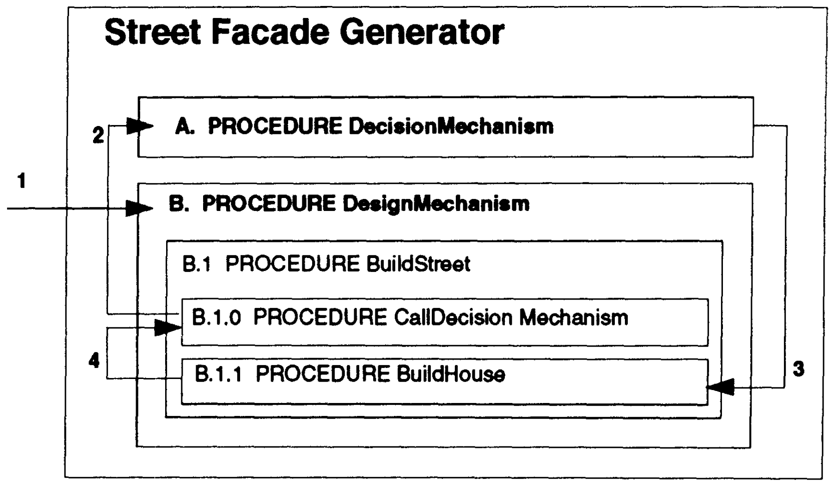


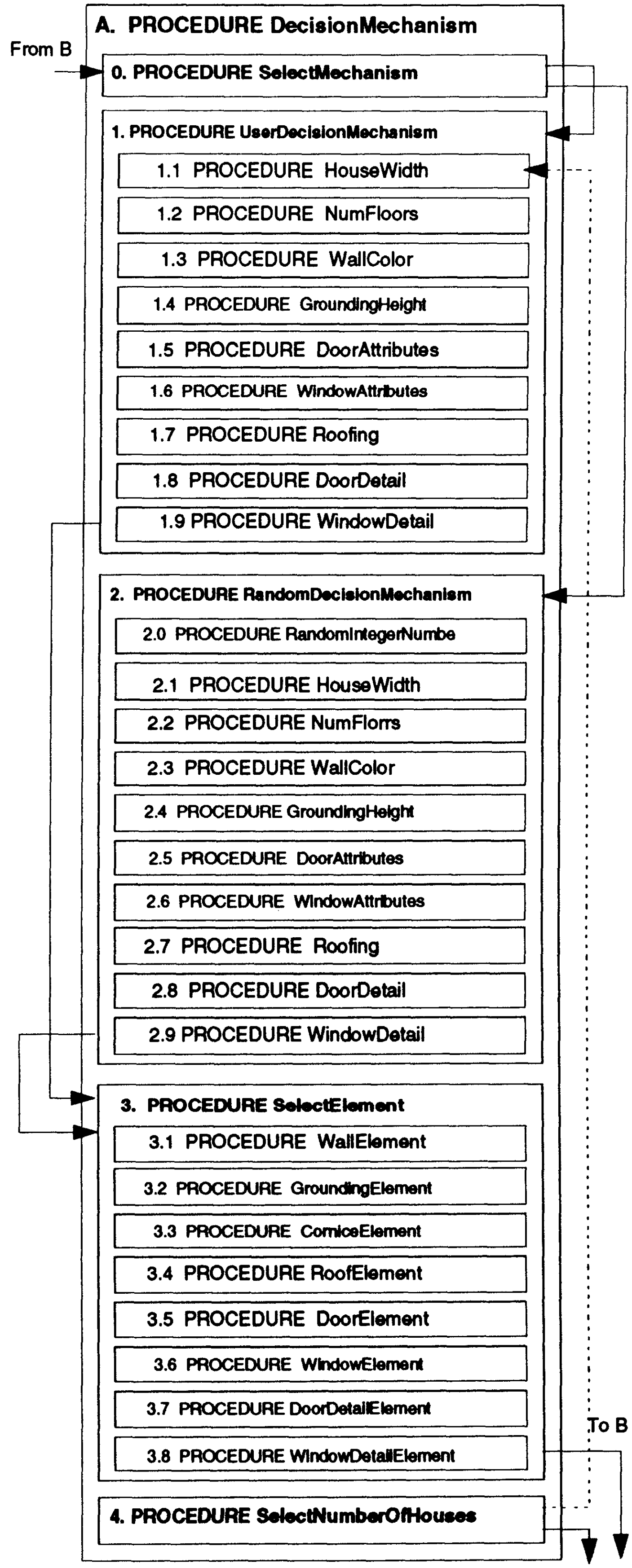
Fig. 9.14
The structure of the Street Facade Generator

We will now describe in more detail the Decision and the Design Mechanisms.

a) Decision Mechanism

The Decision Mechanism is composed of five main procedures: the MainMenu procedure, the User Decision Mechanism, the Random Decision Mechanism, the Select Elements Mechanism, and the Select Number Of Houses procedure. The structure of the Decision Mechanism is diagrammed in Fig. 9.15. and the functioning of each main procedure is separately described below.

Fig. 9.15
The structure of the DecisionMechanism



a.1) PROCEDURE Main Menu

The PROCEDURE Main Menu displays a dialog box (Fig. 9.16) in which the user is asked whether he or she wants to use the User Decisionm Mechanism, or the Random Decision Mechanism.

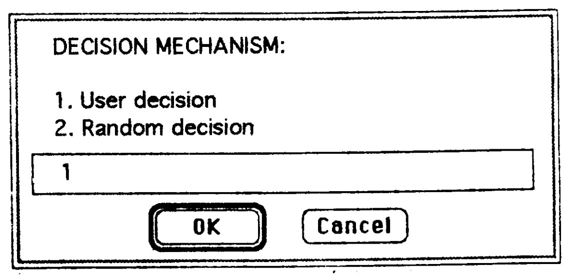


Fig. 9.16
Main menu dialog box

a.2) User Decision Mechanism

The User Decision Mechanism asks the user to select the parameters of each house by means of dialog boxes, according to the decision tree diagramed in Fig. 9.18. At each node is displayed a dialog box. The dialog box displayed at the starting node is shown in Fig. 9.17.

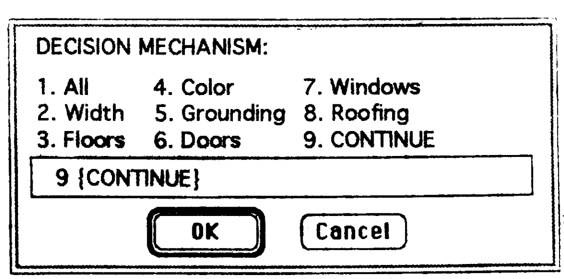


Fig. 9.17
User Decision Mechanism
starting dialog box

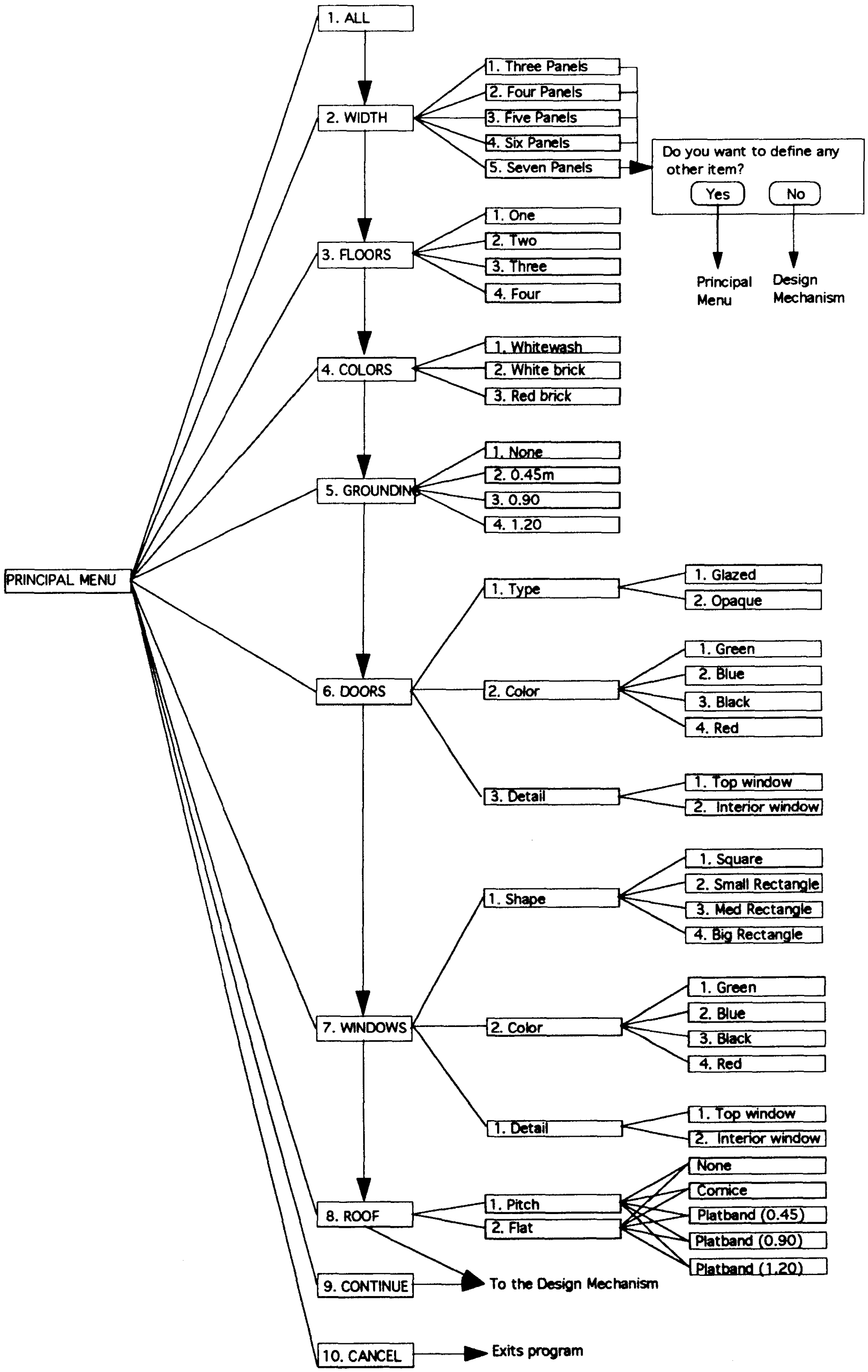


Fig. 9.18
Decision tree of the User Decision Mechanism

Basically, the user has two choices: either select all the parameters, or only a few of them. In the first case, the computer displays sequentially all the dialog boxes required for the selection of all the attributes whereas in the second, the computer displays only the dialog box for the selected attribute. Each of the attribute dialog boxes has a default value that is used if the user does not select any value himself. One of this dialog boxes is shown in Fig. 9.19.

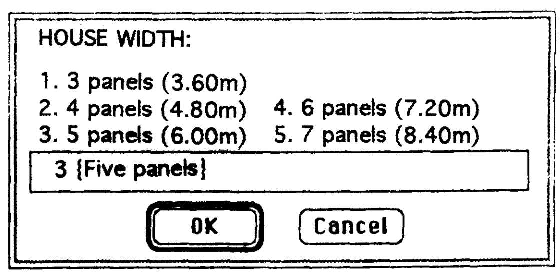


Fig. 9.19
Attribute dialog box (width)

If the user types a character different from any of the ones displayed in the dialog box, the program gives a warning message and asks the user to type a new character. After the user selectes the desire parameter in attribute by attribute procedure, the computer displays a dialog box asking whether he wishes to select another attribute. If the user selects *yes,* the program returns to the principal menu, and the procedure described above is repeated. If the user selects *no,* the program continues to the Design Mechanism. The Principal Menu also offers the option of cancelling the design session at any time. The User Decision Mechanism is composed of nine procedures, one for each attribute, as shown in Fig. 9.15.

a.3) Random Decision Mechanism

The RandomDecision Mechanism is an alternative to the UserDecision Mechanism that randomly chooses the attributes of each house by calling a procedure that gives a random integer number. In a way similar to the UserDecision Mechanism, it is also composed of nine procedures—one for each attribute, as diagrammed in Fig. 9.15. Each of these procedures calls the procedure RandomIntegerNumber, and then assigns an attribute value to the number given.

The attribute values selected by any of the decision mechanisms are stored in TEXTFiles. Each time the program is run it opens the TEXTFiles, reads the values and then turns them into the default values in the attribute dialog boxes. So, each time the program is run, it has the ability to regenerate the last street defined. The user can then modify only some of the attributes in order to study their effect on the overall design.

a.4) PROCEDURE Select Elements

The PROCEDURE SelectElements chooses the design elements according to the attribute values selected either by the user or the random mechanisms. Each element is a module of the system and has a symbol in a library of symbols stored in memory inside MiniCad where the computer picks up a copy to use in the DesignMechanism.

a.5) PROCEDURE Select Number Of Houses

The PROCEDURE Select Number Of Houses computes the number of houses according to the house widths selected either by the user or the random decision mechanisms, and to the given street length. Thus, this mechanism restricts the house widths values available for the last houses on the street.

b) Design Mechamism

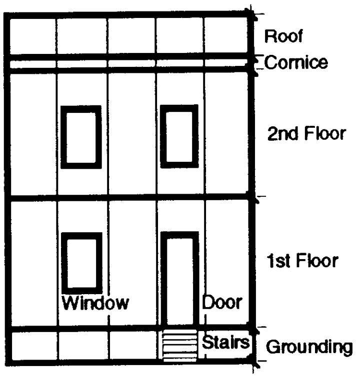
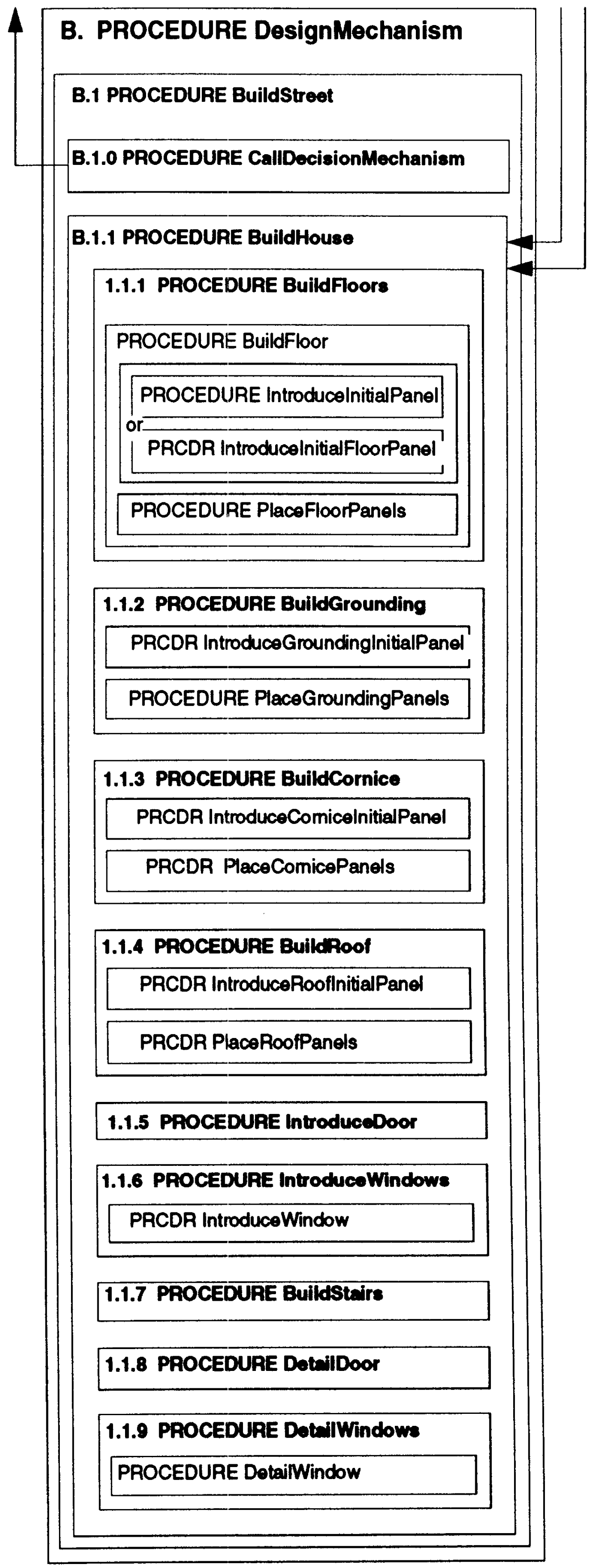


Fig. 9.20
Functional-formal elements of Ana's design

The structure of the design mechanism (Fig. 9.21), follows the schematic organization of the shape grammar which in turn is based on Ana's design process (Fig. 7. 42). The parallel between the program, the grammar, and the design process is such that each procedure in the program represents a rule of the grammar, which in turn represents an operation of the design process. A comparison between Ana's prototype, represented once more in Fig. 9.20, and the diagram in Fig. 9.21 helps to make such parallel clear. Each box in the diagram represents a specific procedure as it is usual in programming diagrams. A box inside a box means that in order to complete the procedure represented by the outer box, the procedure represented by the inner box has to be performed. The inner procedures might in fact be performed several times. For instance, in order to complete the PROCEDURE Build Street, the PROCEDURE Build House, is repeated as many times as the number of houses. In turn, in order to complete the PROCEDURE Build House, the PROCEDURE Build Floor is repeated as many times as the number of floors. Thus, the street is completed after a series of nested loops.

At the bottom of these loops are the basic procedures which correspond to the cladding rules in the grammar. As mentioned above, there is a procedure for each rule but there are only three main types of procedures: one that introduces initial panels, one that places one panel after another, and another that places doors and windows. Despite this classification and the fair amount of rules, all of the rules have a similar structure except the rule that introduces the grammar's initial shape. The structure of the PROCEDURE Introduce Initial Shape is diagrammed in Fig. 9.22, whereas the general structure of the other rules is diagrammed in Fig. 9.23. By comparing the two diagrams, one can see that even the structur of the PROCEDURE Introduce Initial Shape is a

Fig. 9.21
The structure of the DesignMechanism (Buiding Mechanism)



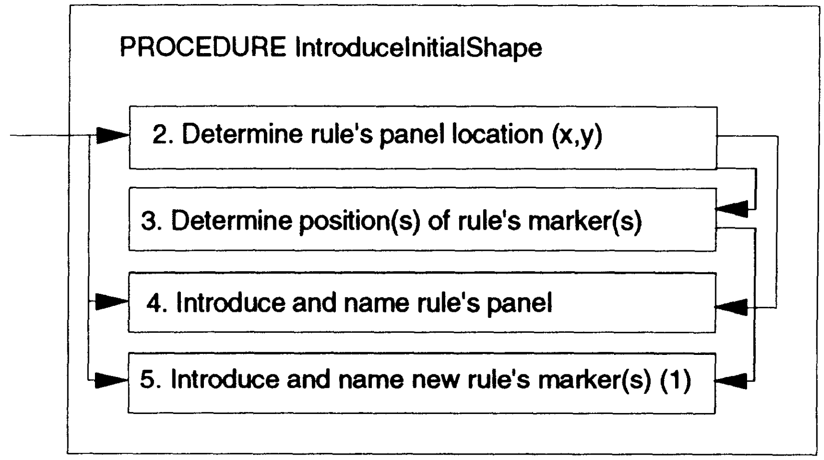


Fig. 9.22
Structure of the PROCEDURE IntroduceInitiaShape

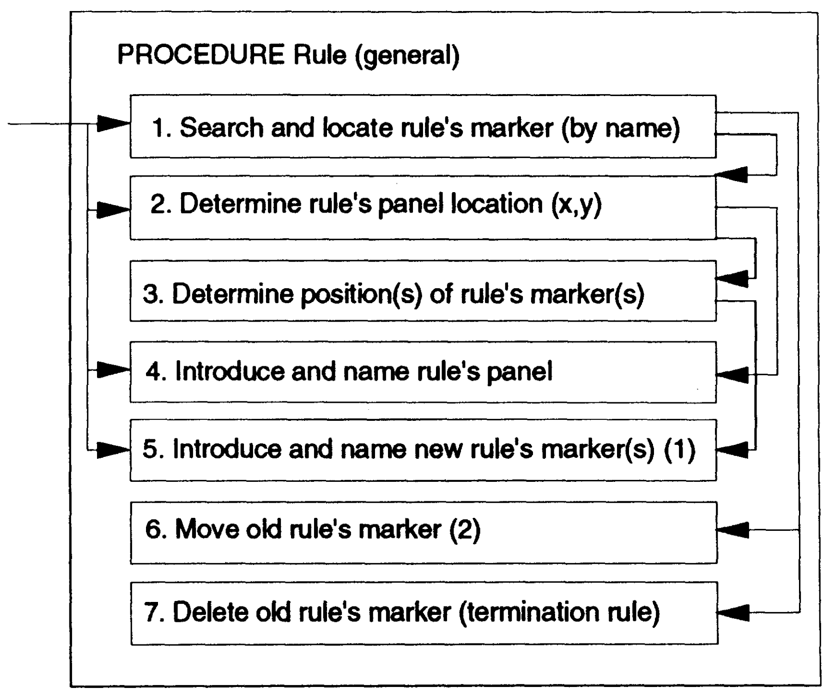


Fig. 9.23
General structure of rule's procedure

variation of the general structure in which the first steps are supressed. The specific procedure of all the other rules also derives from the general structure by supressing one or two steps. For instance, the procedures that introduce intial panels do not have step 6 and step 7 (except the PROCEDURE IntroduceInitiaRoofPanel), whereas the procedures that introduce one panel after another do not have step 5. The similarity between the procedures is such that some procedures are used for more than one rule.

All the shapes that are introduced in the design, be they elements (wall panels, doors, ...) or markers, are assigned a name. The names of the panels are based on their location. For instance, the name of the first house's panel is HOnFlOnPanOn (house one, floor one, panel one). The names of the doors and the windows are based on the name of the panel on which they are located. The names of the markers are determined by location and the corresponding rule's name. For instance, the name of the PROCEDURE BuildRoof takes the name MrkrRfOne for the first house.

The naming code is an important feature of the design mechanism, since it is by name that the rule marker required to trigger a given rule is searched and located. It is also by name that the attributes values of a given facade are stored and retrieved if the facade is to be regenerated. We will now present some facades created by the Street Facade Generator

9.2.3 A few designs by the Street Facade Generator

The following set of designs aim at illustrating how the Street Facade Generator can be used to design diverse facades. The legends indicate which mechanism was used in the generation of each drawing, as well as the corresponding user, if that is the case.

Fig. 9.24
Facade by the Random Decision Mechanism (without windows and door detailing rules)

Fig. 9.25
Facade by the Random Decision Mechanism (without windows and door detailing rules)

Fig. 9.26
Facade by the Random Decision Mechanism (with windows and door detailing rules)

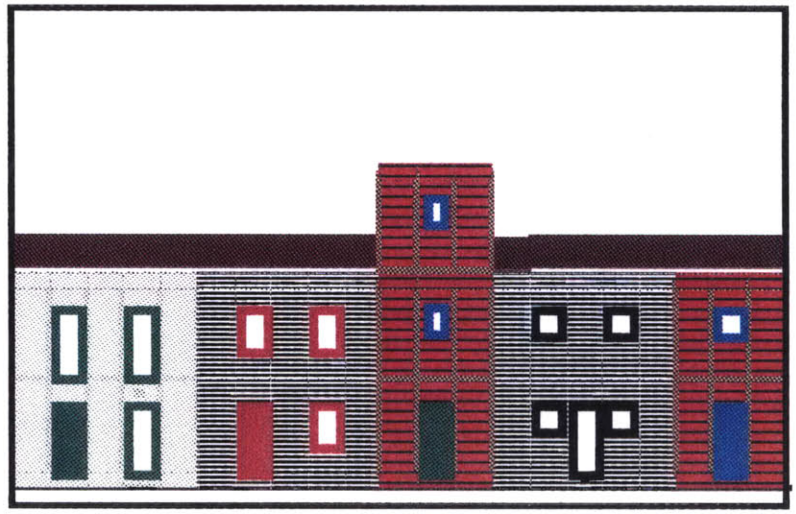


Fig. 9. 27
Facades by the author (1,2,4 and 5) and by the random mechanism (3)

Fig. 9.28
Facades by the author (1,4), by the author's wife (2,5), and by a friend (3)

Fig. 9.29
Facades by the author

9.3 Limitations of shape grammars and the use of evaluation rules

We have argued that a shape grammar is able to generate diverse designs. The diversity of designs presented in the previous section supports, in fact, our argument. We have also argued that a shape grammar also guarantees some level of order. What do the presented designs tell us in this respect? Considering, the definitions of order that we presented in the Section 7, and based on our observations of how the experimental subjects seemed to perceive order, we have to acknowledge that the shape grammar has a limited ability to guarantee order. For instance, it does not guarantee that the street facade is in horizontal balance or that each facade is in vertical balance.

One could certainly argue that is so because we broke some of Ana's rules. Remember, however, that we broke some of her rules in order to enlarge the universe of designs that can be created based on the given set of few elements. It seems, thus, that by increasing the grammar's ability to generate diverse designs, we diminish somehow its ability to generate ordered designs.

This fact occurs because shape grammars' rules are proscriptive rules. In Section 7.2.12, we have already described how such rules have a limited ability to generate diversity compared to that of prescriptive ones. The acknowledgement of such limited ability of prescriptive rules was, for instance, behind the change of building codes from mandatory rules to performance criteria. Let me use this example to clarify the difference between the two types of rules. Consider the following prescriptive rule from an old thermal regulation code: all the exterior walls should be made of 0.15m brick. Compare it know with the new code rule: the exterior walls should be built in such a way as to guarantee an internal temperature between

18^{o}c and 31^{o}c during the whole year. The old rule did not leave any room for innovation; it did not foresee that there could be other ways of guaranteeing thermal comfort beyond the traditional one. The rules of a shape grammar have the same flaw.

On the other hand, proscriptive rules do not give any hint about possible solutions. Ideally, we should have both of them. In order to overcome the limitations of both rules and having their advantages at the same time, I propose to combine them. The idea is to use proscriptive rules as generative rules, since they have the knowledge of how to generate a candidate solution, and prescriptive rules as evaluation rules, in order to check the validity of the generated solution. Taking the discussion back to our problem of order and diversity, what I am proposing is to complement a shape grammar with prescriptive evaluation rules for order and diversity. These rules would be the three algorithms proposed in Section 7: the one for diversity-orderliness, the one for vertical balance, and the one for horizontal balance.

In conclusion, the use of evaluation rules allows the control of the design in terms of order and diversity without constraining the universe of design solutions. In the following section, it is described how the Street Facade Generator could be transformed in order to incorporate evaluation rules.

9.3.1 A more complete Street Facade Generator

The main transformation of the Street Facade Generator would be the inclusion of an evaluation mechanism with the order and diversity algorithms. The tentative general structure of the program in such circumstances is diagrammed in Fig. 9.30.

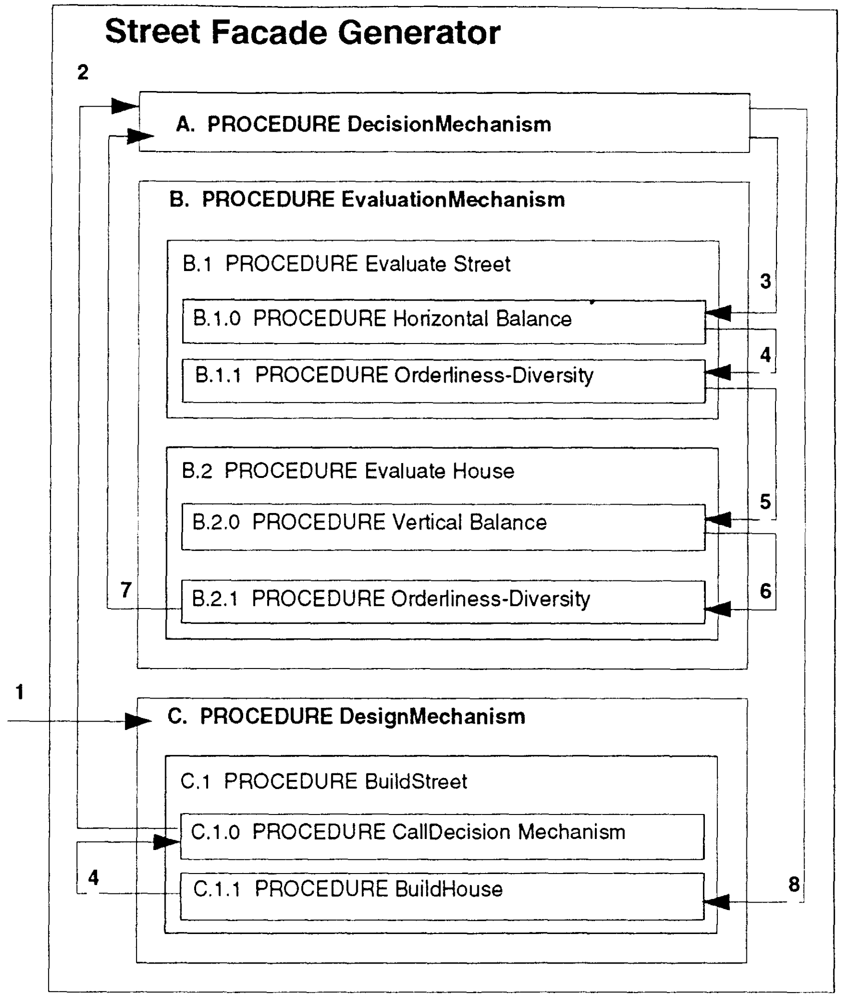
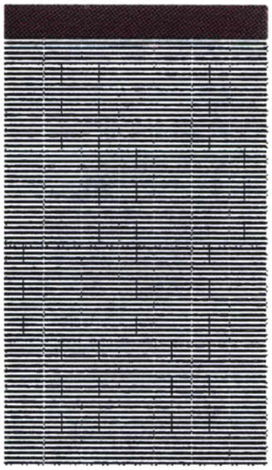
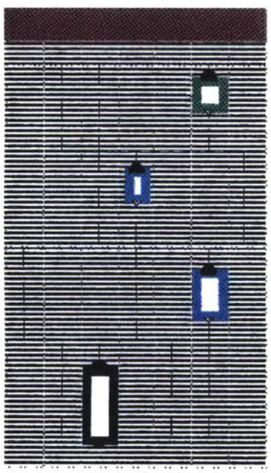


Fig. 9.30
Structure of the Street Facade Generator with Evaluation Rules

According to the diagram, after any selection of attributes made by the either one of the decisions mechanisms, the program calls the evaluation mechanism. Inside the evaluation mechanism, such selections are successively evaluated by each of the evaluation procedures. These procedures compete against each other in order to determine the definitive choice made by the decision mechanism. The weighting factor of each of the evaluation procedures is such that at the beginning of the design process of each design arrangement—house, or street,


A


B

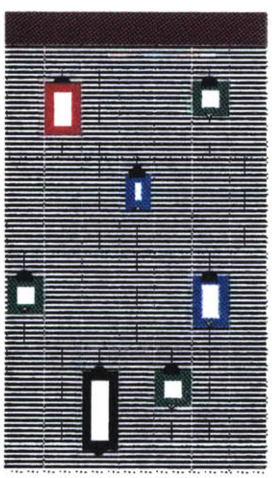

C

Fig. 9.31
Hypothetical sequential placement of windows by a Street Facade Generator with evaluation rules

the corresponding diversity-orderliness procedure has a bigger weight than that of the balance procedure. This weigthing ralationship is then inverted as the design of the arrangement approaches the end.

As can be seen in the diagram, the application of the balance rules are in accordance with the conclusions of the experimental results: vertical balance applies to the houses whereas vertical balance applies to the street.

A possible application of the vertical balance rule is diagrammed in Fig. 9.31. In Fig. 9.31-a, is shown a house after the selection of the wall panels. The panels with a vertical axis (door window marker) are candidate panels for the placement of a door or a window. The distribution of such panels is done randomly, although in a more elaborate street generator it might also be informed by the user. In Fig. 9.31-b the program has already started to place some windows. Note that the placement of the windows is not done systematically, but in a way determined both by random choice, and by specification of the evaluation mechanism. As the placement of the windows progresses, such placement is increasingly determined by the evaluation rules. In Fig. 9.31-c, the program has continued the placement of the doors and windows. Note that the use of windows of a unique color is not necessarily a requirement. In fact, the balance rule guarantees the perception of a certain level of order in the facade, even when different colors are used.

Although the above description of the structure and functioning of the Street Facade Generator is merely hypothetical, it isgiven as an attempt to demonstrate how feasible is the combined use of a shape grammar and evaluation prescriptive rules.

I should clarify that I do not mean that I do not mean that prescriptive rules cannot be used as generative rules. In fact, they can, as demonstrated by Papazian (Papazian, 1991) who proposed a design generator based solely on prescriptive rules that he called Discoursive Generator. However, we would need many prescriptive rules and an elaborate Discoursive Generator to generate a street facade. A shape grammar is more direct, and so a program that supports it is likely to run faster.

Prescriptive rules are more abstract, and are so much closer ti an universal way of designing. But our concern is not the development of an universal way of designing. Our framework is more defined: by the rules of the system, but also by the rules defiend by the designer within the system.

Therefore, for our purposes the use combined use of a shape grammar and evaluation rules has clearly some advantages.

Appendix A

The results of the "Spoken Game With Abstract Elements"

Appendix A.1

Graphic Protocol

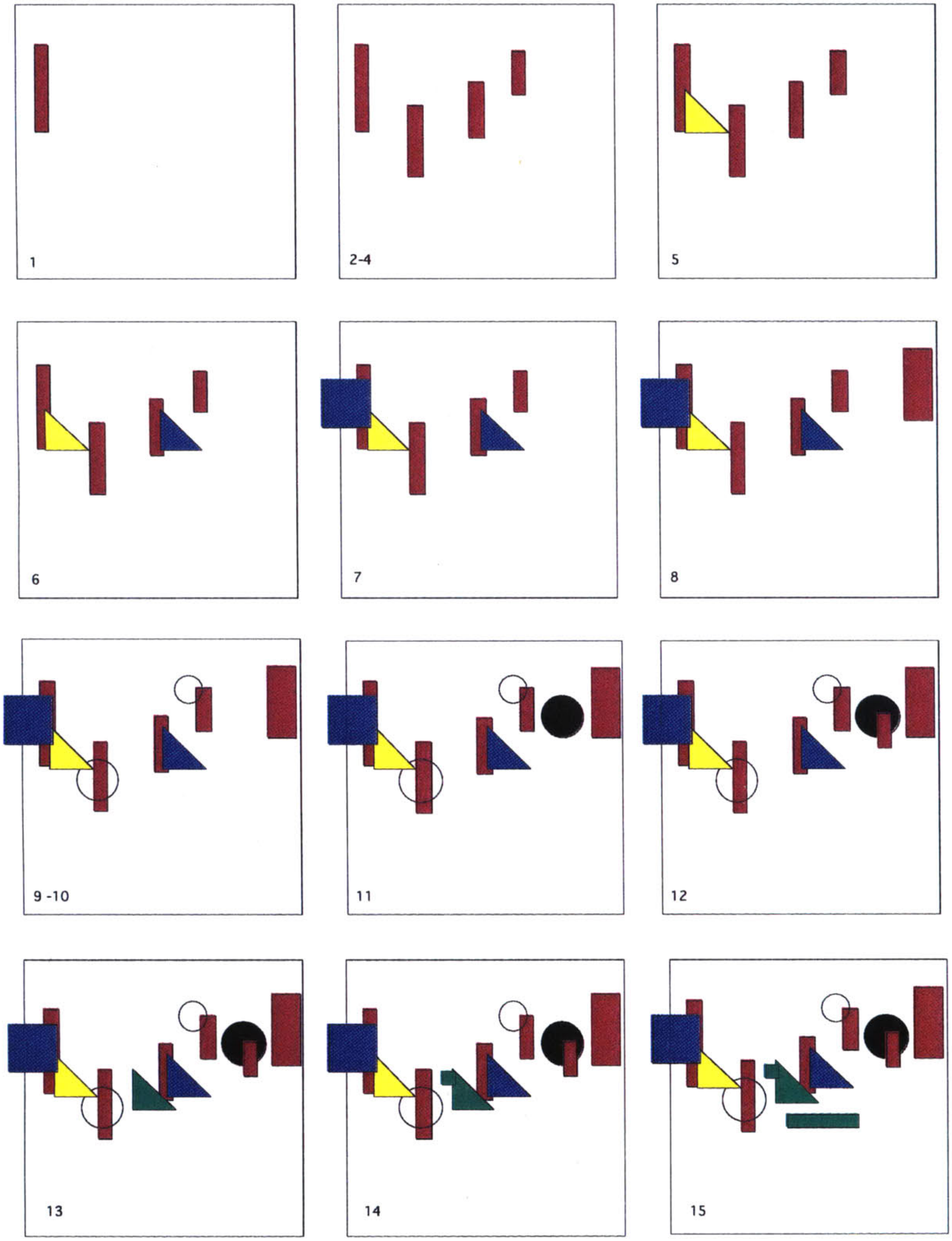


Fig. A.1
Thomas Design Process

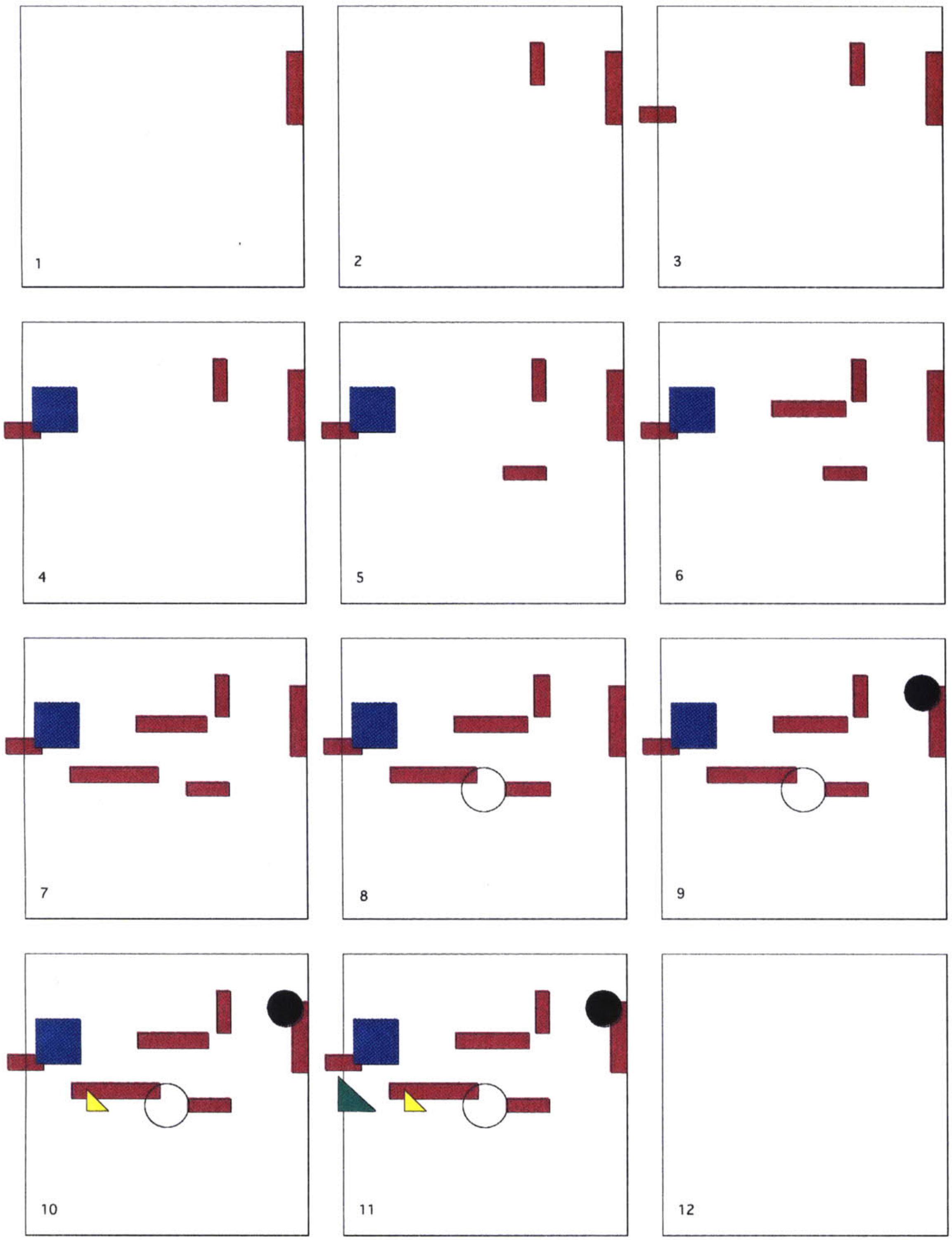


Fig. A.2
Dan's Design Process

Appendix A.2

Verbal Protocol

PART 1

Designer A (Thomas) designing. Sonit assisting.

T: Take one of those vertical pieces from one side to the other

First I am going to repeat those vertical things in that direction.

Looks very much like Maurice Smith.

Some smaller elements. All for the sake of diversity.

Small elements of another color and size.

I am moving in the diversity direction. Is there any color I haven't picked so far?

S: White!

I am working in the connection.

I do not thing it has to be entirely connected. It's already connected. Let's get some more to get it really diverse.

Let's get some diversity by not having one connected at all.

S: What about wholeness?

T: Wholeness? It makes this kind of wavy movement and there is a continuation of people, of red pieces that stand perpendicular to the main direction of movement. That should do it for wholeness. This guy (the computer) doesn't really help, so let's move it.

Designer B (Dan) watching designer A designing. Jose assisting

J: He has a design task and you have to pick up what the design task is and replicate with your design using the same rule he is using and doing the same design task.

D: I can interpret the rule but I can't guess the task.

J: He has to connect two points on each side of the screen. From the left to the right.

D: Oh I see, it is something as simple as that.

You are going to tell me when to start.

J: Yes.

D: So, I am going just to watch now.

He is getting the thing where he wants it.

It looks he is setting up a musical rhythm. I haven't a clue. Did you tell him he has to get from one side to the other?

J: yes.

D: Is this an analog for a three dimensional thing, or is it a purely two dimensional exercise?

J: It's up to you.

D: See, I don't know if he is working in plan or in section, which is interesting.

Now what's he doing? It seems he generates a series of stops, rather than an access. When you first said, one of my reactions, might have been to put, or a possible reaction would have been to put an element that even went, there by establishing completely the dimension, building the complete dimension and then begin to generate some kind of system of stops and access that would get, I'm thinking in plan now, although could be the same in section, but he has done a kind of different thing, he started initially by generating from one side to the other then it seemed like he stopped, changed his mind and built tears the time to the end. Does he have a time limit?

J: He has much time as he wants.

D: Oh, Oh! It could be, now suddenly I am seeing, it could be an elevation that he is making. This could be an elevation, I am sorry not an elevation, but a perspective or an axonometric. I wonder if that is the case. Now that he is putting all these elements it seems almost as if there is a depth, a picture plane depth, perpendicular to the picture plane. I wander...

J: Now, he made a mistake, he is not allowed to change the size of the elements.

D: But it is okay for him to be touching the edge, no? Now he has actually broken the plane. Is that also acceptable?

J: yes.

D: Could he begin to work this way across the whole screen?

J: No.

D: No, when... At this point, it seems like I am not really seeing a significant development since the initial move, since to have been established now he is sort of filling in, almost iteratively, now and there, the initial path has not change since he stopped using the red. Almost, I am clear at this point as to the way he is accomplishing the of the elements, whether it is some way systematic or whether is just more intuitive. It seemed he was intending some systematic moves with the red elements, having trouble in picking anything of that nature now. Certainly, in terms of dimension is difficult to figure out of kinds of rules he is playing... It seems that the reds are structural and the other elements are, somehow, secondary elements. It is interesting he hasn't altered the red elements since he stopped using them. It is the first time he is using another rectangle (the green). If this is in plan or in section, there is no clear route or access from the left edge to the right. The structure doesn't seem very coherent at its largest dimension and he hasn't changed it since, it's beginning too be more packed, but I am not sure to understand what's being accomplished by the packing. This is the first significant element that is directional (green rectangle) in the state of the direction of the assignment as you describe it to me because all the other elements were either the red ones or...

He has finished. Now are you going to explain the task more what thoughroughly or do I have to use my interpretation with the little bit of information that you gave me?

J: yes.

D: So can I alter this to whatever extent I desire?

PART 2

Designer B (Dan) designing.

J: Okay Dan. That's your turn now.

D: Okay, so now. Using any elements?

J: Yes.

D: Not just the one he has?

J: It's up to you.

D: So, I could... If I wanted I could start from scratch? But I won't.

J: You can do anything you want, but you have to pick up... refer to what he did, and as you know you have the same task which is to connect the two sides of the board, and you have to replicate...

D: This I can move without cutting and pasting?

J: No. You cannot move his design?

D: Oh, I can't?!

J: You cannot. So, are you having troubles with space?

D: Yes. For me at this point I would try to open the center of this up a little bit, and also to reorient some of these elements.

J: Wait. I had an idea. But, you will need to see it.

(removing Thomas' design from the drawing board)

D: So, am I going to loose his (design) entirely?

J: No, what I will try to is, do a new one, copy this one, and...

D: But I won't be able to see it as I am working? I thought it would have been relatively interesting to take the ones he had, and shift them around.

J: Oh, I see, you don't want to use new elements.

D: Not necessarily. I just wanted to be able to shift what was there.

J: Let me think. I think you should not destroy his composition.

D: What you are saying is, I have to use, these all must remain, in other words.

J: you should not destroy his composition.

D: But his composition is already saved, right?

J: Yes, but that is not the problem.

D: Humm... I hope I am not making this more difficult than...

Can I have a new board? Without a new board I can't react to what he had, except from my memory of it.

So, I'll operate mostly by memory. So, my first assumption was...

J: Wait. I have an idea.

(placing Thomas design on the side of the screen)

J: Can you see his design?

D: Yes.

(re-arranging the different windows)

J: Okay. Let's start.

D: I can't talk and work at the same time.

What I am trying to do is to take Thomas' initial conditions. I assuming this element on the right to be his last structural move. This my assumption, that the red is structural. I can't change these orientations, I take one of these, instead?

J: Right.

D: What I am trying to do here is still to use these as structural elements, I am going on the assumption that this is in plan, and that he wasn't doing some more spiritual illustration or simulation of space.

I am going to keep this assumption about the red being structural and I am going trying to set up some kind of direction to the... the implication being if I am connecting this I want to have some implication of the direction of getting from that side to the other. This is, either is structural or not, it seems a significant element, a starting point (the blue square).

I am assuming the red elements to be structural, we are speaking in analog here. When I say structural, I mean there is somehow a... you started with them... Since he started with them, my impression was they were a way, for him to establish a basis, a framework of which he could then continue to work, and I am trying to maintain that as an understanding. Where he had them as I see a series of stops almost a he is establishing the direction because of this rhythm of stops, I am trying to incorporate some directional aspects as well, and maintain this large red element as a more definite stop to the end, so that this blue element and the red element essentially are the end points of the system. Now, let's say I am going for the sake of border, to say that's it as far as the framework (putting red element on the right). I broke up of using the framework for that blue square because I saw it as significant.

Now, I am seeing these other elements that he has used the triangles and the circles, and the small square, frankly I am having a hard... I still don't see system and I am wandering if possibly they are more intuitive. Assuming that's the case, I am not sure that many are necessary, I mentioned earlier that was a packing going on. That's something significant about this empty shapes is that I am curious as to whether he has used as a volumes or... indicating a volume or just the perimeter. I am going to assume that there is some kind of screen element, less volumetric, or less opaque than the other. Where I have just placed it the implication is that there is a closure between these two red elements but as not as intensive closure as solid or opaque.

Let's see, he has also used one of these black elements. I think that is fairly significant how he has used it. Is it going automatically to seat behind or on the top of it? It is on the top isn't it? That's interesting! He must have put this last red piece in later. I had in my mind that this recollection of all the red pieces went in first, which in fact they didn't. And the way I have done it so far is that the way I have done so far is that the only thing that went in before I stopped using the red pieces was this blue one.

I am just about done. I'd love to use a triangle just because he went first and I want to use all the elements he has used, so I hook to that a little bit more capricious.

There is another factor here. I don't know if this is part of the experiment but there are codes here, and he has used one of each of the colors, which I haven't. And I haven't decided if I stick with that or not... Let's use one of each has he did. It must have been one of his rules, may be not (picks up the yellow triangle).

So... green is left. This is going to be my last move. I have also chosen to break that edge because it implies some further possible beginning here with the hard end here, so that's why I put the black circle at the end.

Designer A (Thomas) seeing Dan designing. Sonit assisting

T: First he put the vertical stick, the red one. He is completely copying.

He has just laid the horizontal red stick, the second one. He is going along, copying my design.

The blue square. Formally is very similar, he uses a lot of similar things. Are the horizontal and vertical red sticks considered to be the same entity, no?

See, what he does, either he hasn't understood it , which is possible, but I don't think so, or he just works in a different way, he doesn't set up this kind of, he doesn't work as methodological, I think he has a compositional idea. He is balancing this thing while he is going.

I was finishing one move, then I was adding other stuff to get this diversity thing. Maybe he has a picture of whatever he has understood this to be in the back of his mind, and he is filling it up and he is checking it while he is going. Plus he seems to rectangular fixed, just because he is a fascist design, that's what he claims.

He is going from the right to the left, I went towards the right, but this doesn't make any difference. He is doing a lot of similar moves. He is establishing the whole by the reds sticks. From the beginning he has added at least, what is his idea of diversity. If you have random distribution with one of those colors, then you end up with diversity.

He is absolutely in the right track. It is good he is not following the formal set up of this thing. Obviously there is some idea behind it but there is just using this to be transported.

Maybe there is a lot of redundancy in there, there is much less redundancy in that one. He uses minimal set up, which I think more appropriate for an answer, for an explanation. This is a kind of a test.

Now, he is looking at smaller sizes.

This is a strange move, it is a kind of obscuring what he got before. If he does that he has to do a lot of other things. He has just put the right circle between two red sticks.

Is he going to put between to red things again? Black circle.
I wander why this white thing is transparent. He does pick the same elements, he does use them differently, at least that is what he did at the beginning, now he is getting more continuously in the same way.

I think that this has a much more spatial understanding. Mine was more graphic. This seems to me at least, much more architectural understanding if you look at it as a plan or as a section.

He has something in his mind, the white space is considered

I think it is a good response, I think it works. I think he could have tried out a little bit different formal material.

Discussion.

D: It is tiring, isn't it?

T: Yes!

T: He did what I expected. Two things: First, I set up rather methodically in the beginning and he picked up the basic things in a minimalist way as a test to why this thing meant. Second, the elements were very similar to the ones I used, but the spatial set up is different. Mine is really graphic his is more spatial. The minimal response was altered a little to kind of variating in the same thing, that worked pretty well variation

D: First I was unclear you were implying simply a plan or a section. So first I assumed it was a plan or a section. And then all of, most of these red things went first to the point that I forgot that these one came later. So, then I thought that these red ones were somehow structural or a framework. And I was told simply that you were trying to get from this side to this side. And I noted that you went part way and then put this one in, and then you started to work back. So then after you put this pieces in, I thought for a second or for a few minutes that you were implying like a painting, some kind of depth, but I later discarded that as a possibility. So then I started working the first piece I put in was this one, at the far right because it was very significant, because there was this stop at the end and then I put blue one in not touching the edge, because I thought it was a sort of a start but not of one these structural red elements. Then I started to put the rest of these in then I felt I that I wanted some direction or some access, I was really seeing it as a plan,

T: I red that I thought of it as a plan all the time.

D: Them I assume that these other things were more some type of infill, perhaps more intuitive, and so I based on that assumption I started to use them after having established the framework, and I was telling this to Jose, that why he then saved, before I started using them. Then I made another assumption...

T: But then the blue square was in the framework.

D: I didn't think it was part of the framework in the structural sense but I thought it was so significant to the overall task. Then I didn't know how you were seeing these empty ones but I assumed they were potentially closure that was not opaque closure.

J: Did you them transparent or you thought they were opaque.

T: First, when I picked them I thought they were going to be opaque, but then I liked it much better, because I didn't really have any real architectural metaphor connected to that, this were more graphics that I did. But I was thinking of connecting and disconnecting and so I was thinking and figuring how, at the same time, so it was important to me that were not connected overall that some of them were standing singular and some of them were connected. But I was really surprised about that move (empty circle).

D: I assumed this to be architectural, some kind of proposal for something built. Then, I felt I would put this here as a window or something, a closure that connected these two, but was still this connection but not as hard. Then I took this black thing, at this point things started to be more capricious, less considered, I put this here as an emphasis to this stop, to this end, and also because I wanted to differentiate between how open this opening to the lower zone wasn't...

T: Yes.

D: I noticed that at this point you have used one of each color.

T: You picked up the small...

D: Yes, it was almost impossible to move it around. So I put it there, then I picked the green, to have also a green element, and put it here again, just, just to,... more intuitive than anything else.

J: You were not thinking about a plan or a section.

T: No, I have told that. Mine was more of a graphic thing or a perspective, or something...something not tied to a section. As a matter of fact, I was thinking about this things as verticals...

D: That's what I thought in the middle...my middle assumption. Instead of this seeing it a two dimensional drawing, all of a sudden, I began to see it as a representation of space.

T: That has happened at the same time, I started it out as a kind of abstract texture. I was trying to establish this thing from A to B, ...

D: ...that's how I saw it, as rhythmic generation of the connection...

T: ... that connects better than a straight line, and if you have things that go in the direction of the connection then you'll have less options to fill in later. So that was the kind of set up for this "s" form. As soon as I put in the triangles it hit me by surprise by surprise as well, that they were this kind of tectonic, and that they had a bottom and a top, then it became more of a perspective view.

The thing that gave me the biggest clue about your special thing was this strange empty circle closing off two pieces. Before everything was really graphical. Even though I had the feeling it was a plan but it didn't get this... it was like a move from a conceptual sketch to an actual working drawing. In the beginning I thought he was going to use all the elements that I used

T: You can't test an hypothesis just by copying it, you have to have an alteration, just change one parameter, and then you might have a clue.

J: One last question: do you think they from a whole?

D: A whole, what do you mean?

J: Besides telling Thomas that he should connect the two sides of the screen and make it diverse, I also told him that should look a whole.

T: This is interesting to me. As soon as Thomas put this blue square beyond the edge of the thing, I said: 'can he do that?' And he said: 'yes!'. Then I said: 'could he just keep going?' And he said: 'he could but it wouldn't be...' And as soon as you did that, that became very significant to me, and chose to put these beyond the border on purpose, because here there is this hard stop, and this is some implication of possible...

J: Was that intentional?

T: Yes. I had this as an end, and I put that blue thing in order to get a whole and balance a little bit, but then I thought if this thing is really going to connect these two than it more than just stopping, so I put the blue thing over the edge, because I thought it is really going to connect them if it starting somewhere else. I thought it was really interesting that he was going back, he kept the spatial configuration with the overlapping on the left, but you were moving from the right to the left, so you basically B to A.

D: He said to me "don't destroy his thing", he didn't want me to start from a fresh screen. Given that in some ways it became easier because it became like doing a [...]. I could look at what was happening, make some assumptions, and then start changing something.

I thought that this stop was one of the most significant elements in the all thing. This goes back to what we were talking about last week. I always try to understand any design problem at the largest size first. So, that's in fact when he was working, I had some confusion at the beginning, I couldn't understand, then he jumped over, his was not entirely different, you didn't work completely from A to B. You worked from here to about there. That reminds me of the discussion that you and I last week about my problem. In order to establish an understanding of the dimension, you need to build the limits of the dimension, and then work within that limit. Otherwise it is just like coral growing or it's just a path, rather an actual understanding of the design problem.

J: One last question. Thomas was it intentional to enlarge this element. It was a mistake?

T: You can say it was an opportunistic move. It got bigger than I wanted to have in the beginning but then I was very happy with it, because it was final piece, that's why I put all the way to the side.

D: Oh!

J: It was not intentional...

T: No, but once it was there I was going to use it.

D: It was that generated your intention to go to the end?

T: It might have been?

J: Why didn't you use more elements like that?

T: I thought that this diversity question, was to be dealt with carefully, because if you get random distribution you don't get diversity. You just get random distribution. That's why, for instance, that when I alternated the colors, I only did in triangles of about the same size. I had only one really small size. I think that diversity is if you have a majority and small minorities. So that's in there somewhere. This all set up is a kind of a community of elements that are very much ruled by some sort of rules.

J: Is it the size of them?

T: No, it is not the size but from taking out of the family that's generated by some kind of rule, which is basically the set up for this experiment. You can have elements that change in this framework, but if you change the all framework, you are not getting diversity at all, you are getting some kind of science fiction.

APPENDIX A.3

Graphic and Verbal Protocol Analysis

Graphics

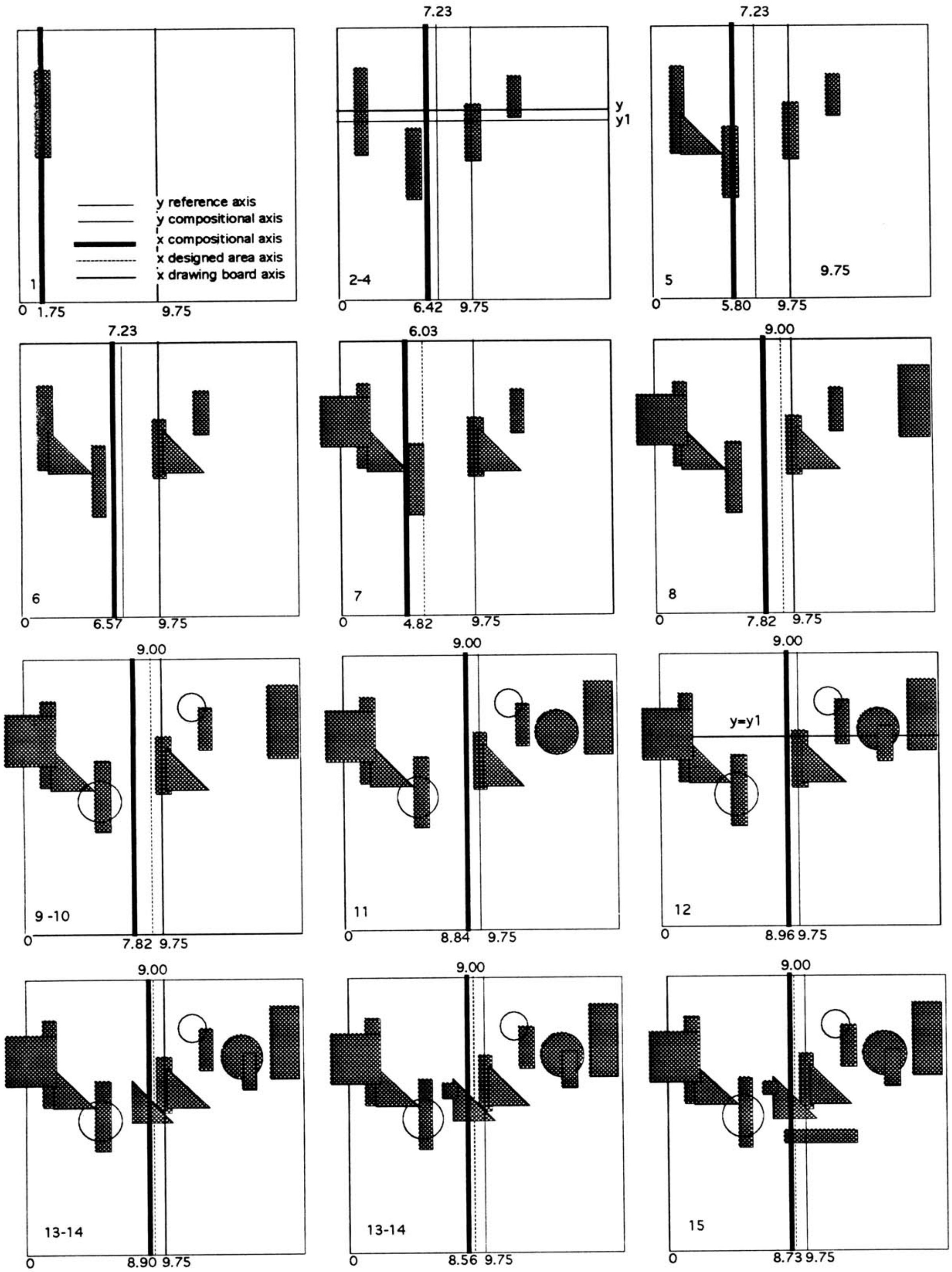


Fig. A.3
Analysis of Thomas' design process from the viewpoint of vertical balance assuming that different colors have the same visual weight

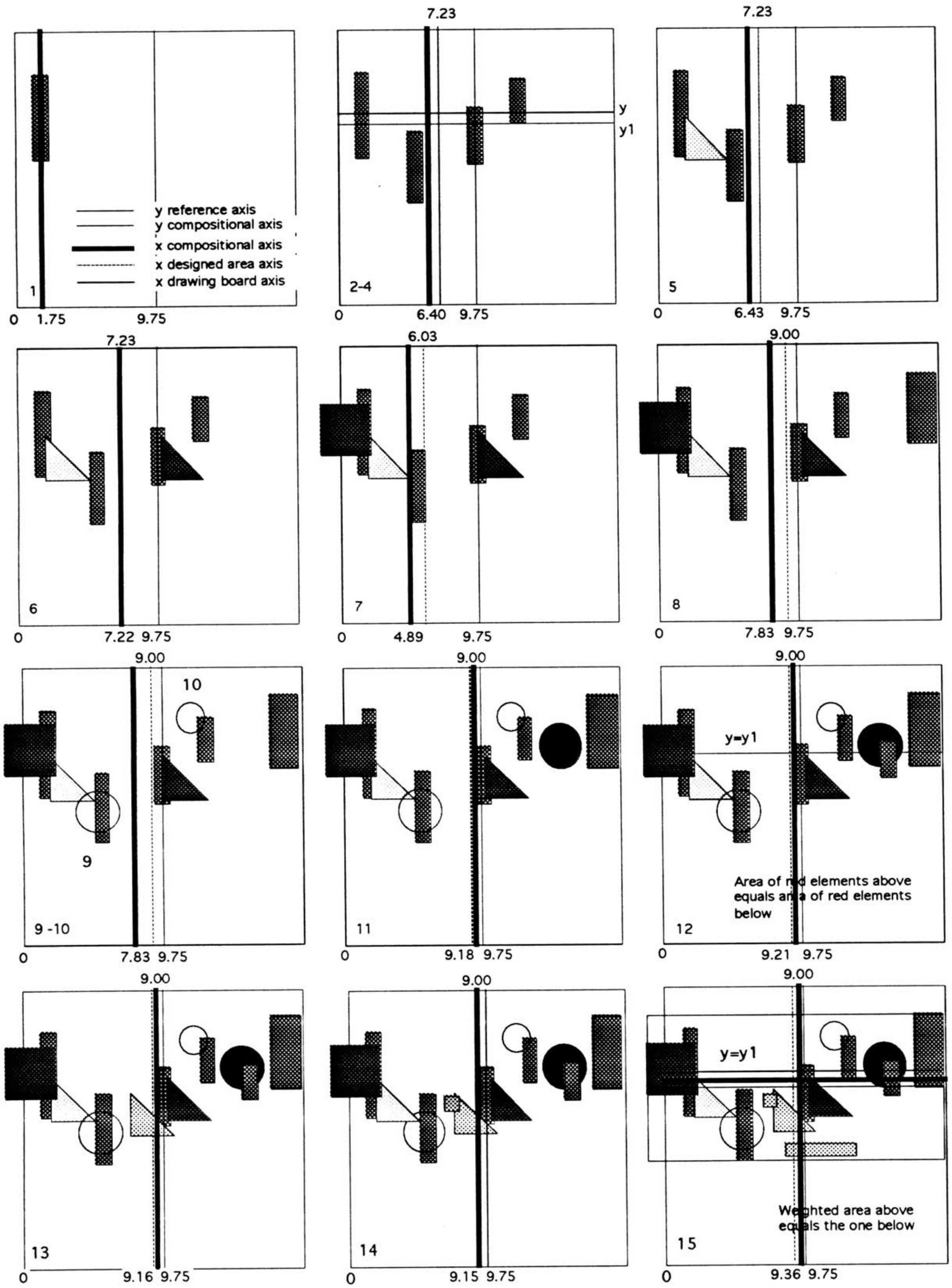
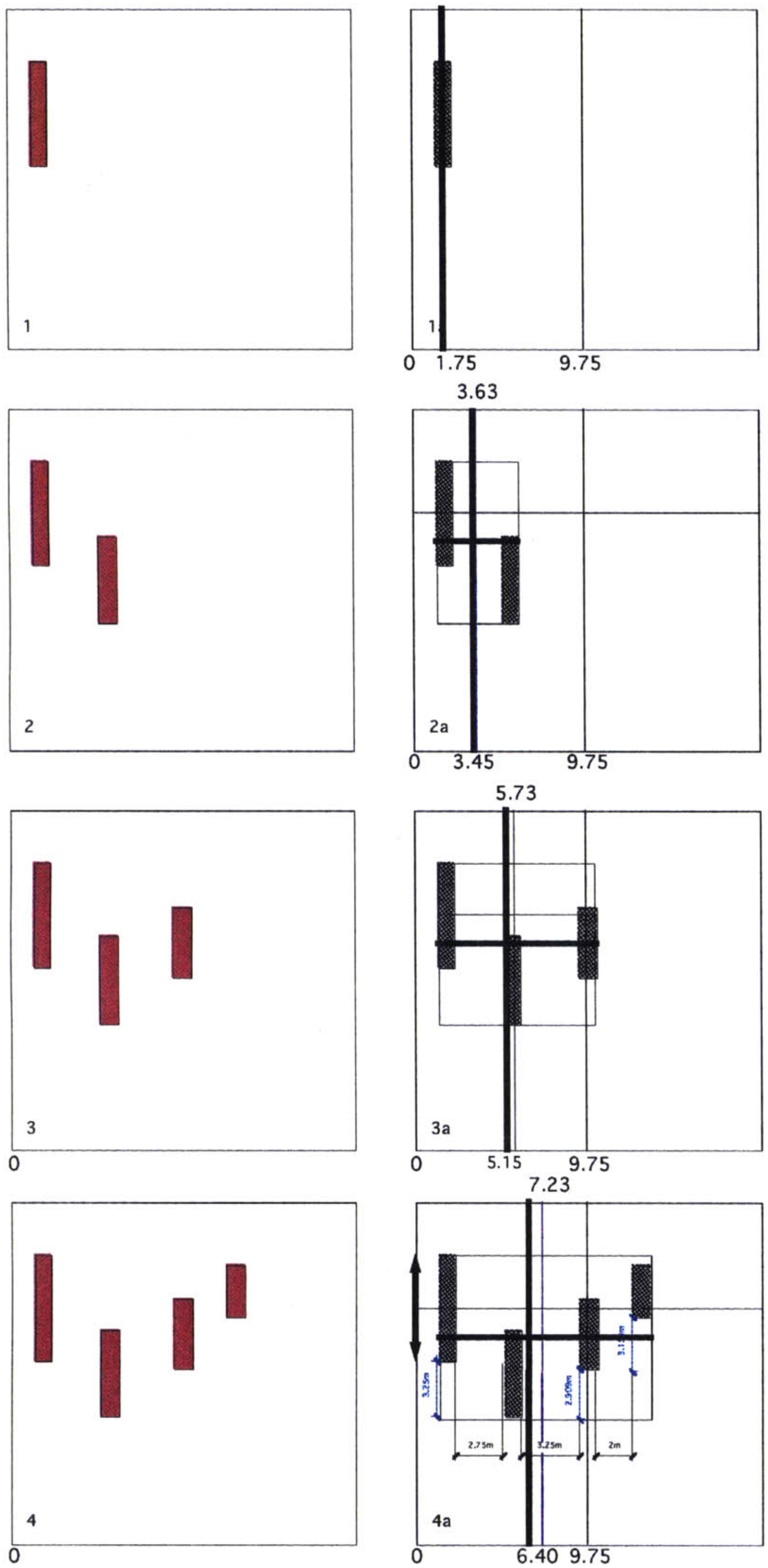


Fig. A.4
Analysis of Thomas' design process from the viewpoint of vertical balance assuming that different colors have diferent visual weights



Legend:
- y compositional axis
- y designed area reference axis
- y first element mid-point reference axis
- x compositional axis
- x designed area reference axis
- x drawing board reference axis

Defining the "framework"
Attributes: shape, color, size (height and width), and location.

Diversity:
a smaller element placed below.

Order:
given by the use of the same color (red), the same shape(rectangles), and the same orientation(vertical).

Diversity:
Relative Location:
Vert.:up-down-up
Horiz.: smaller distnce between the third and second elements.
Size:
decreasing height

Order:
Color: red
Shape: vertical rectangles
Balance:
Vert: unbalanced to the left
Horiz: unbalanced to the botom (mid axis of the first element seen as reference)

Diversity:
Relative location:
Vert.: up-down-up-up
Horiz.:decreased-enlarged--decreased.
Size:
decreasing height

Order:
Color: red
Shape: vertical rectangles
Balance:
Vert.: unbalanced to the left
Horiz.: unbalanced to the bottom.

Fig. A.5
Graphic Analysis of Thomas' design process

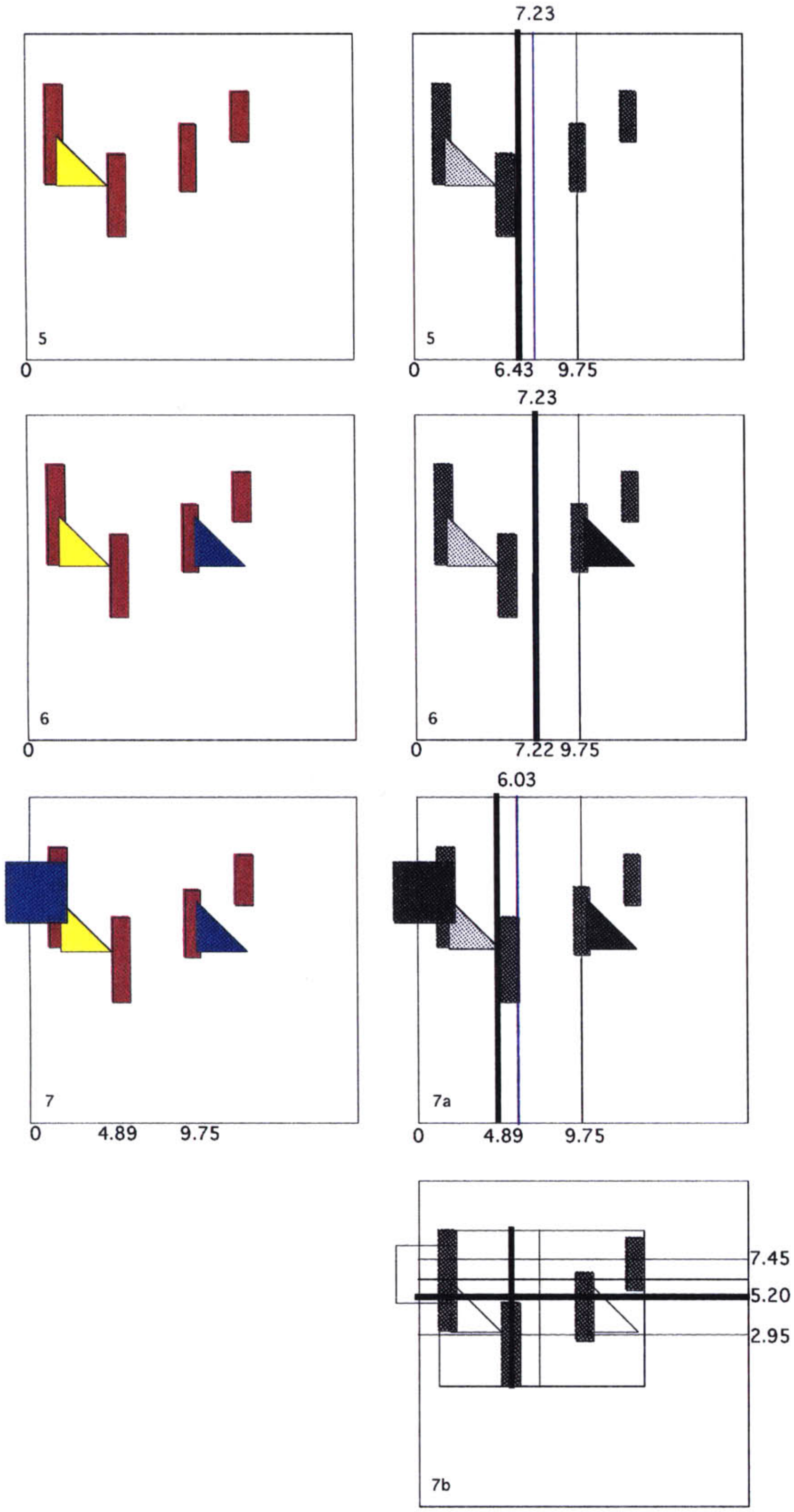


Fig. A.5 (continued)
Graphic Analysis of Thomas' design process

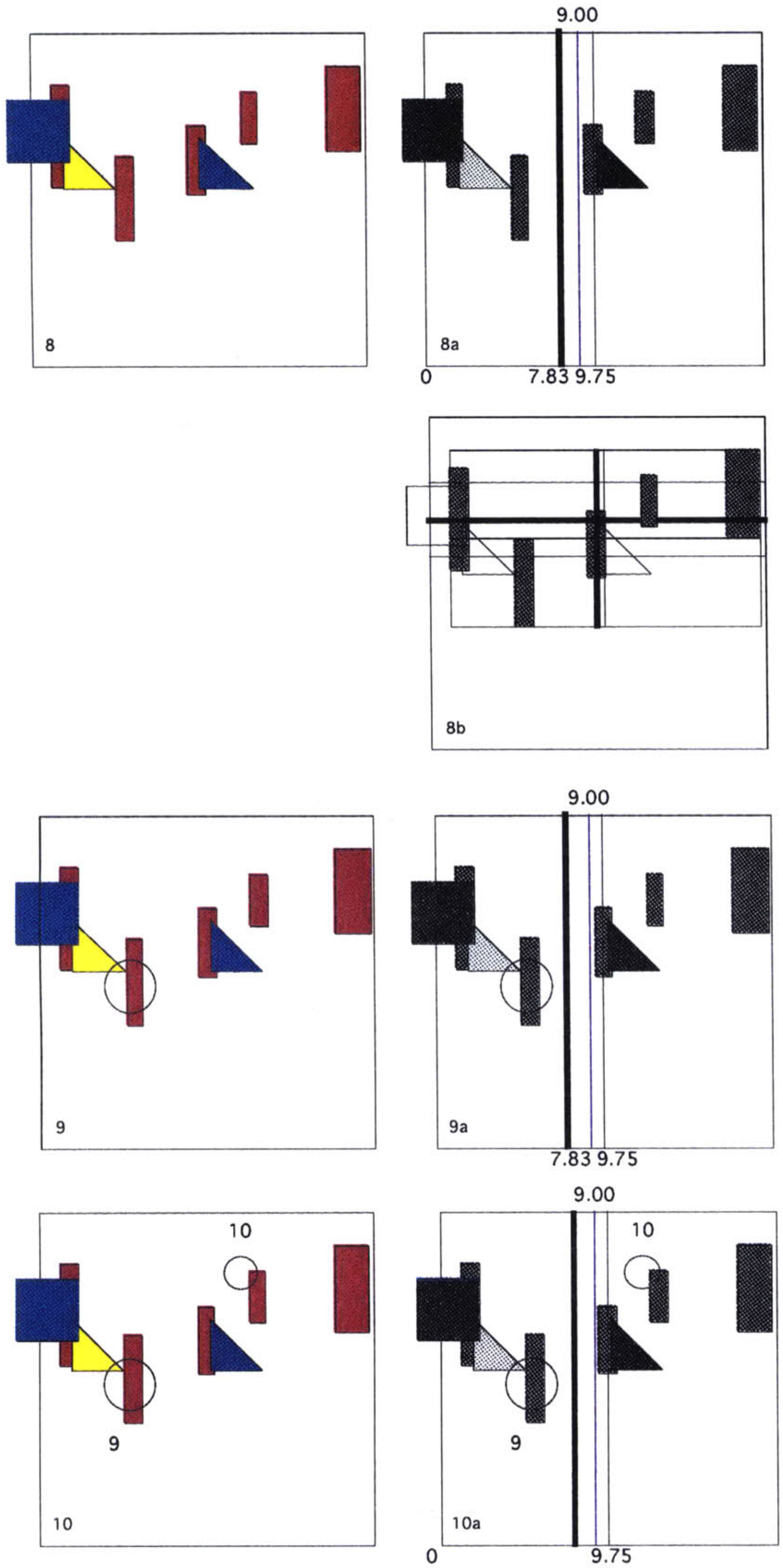


Fig A.5 (continued)
Graphic Analysis of Thomas Design

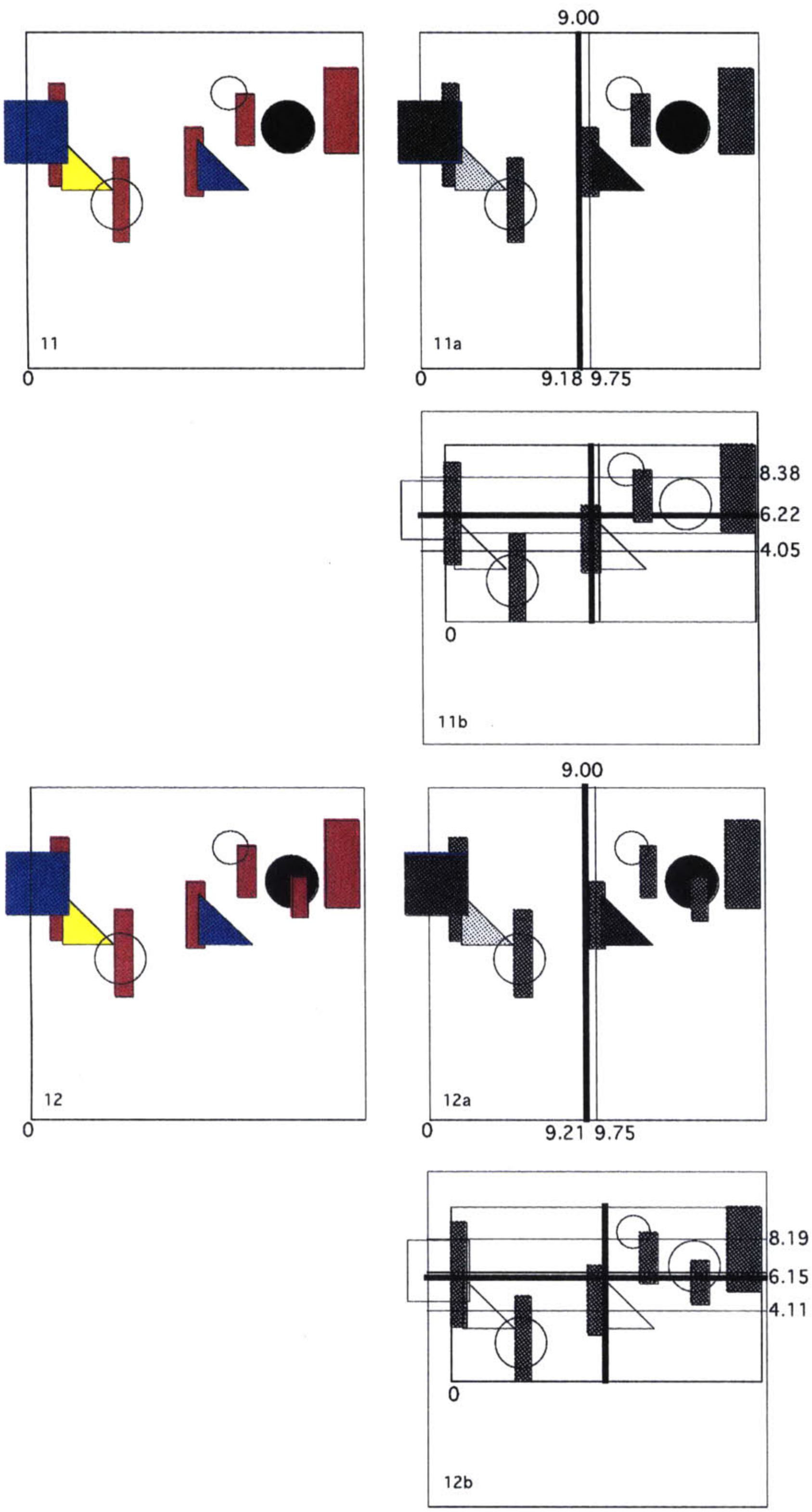


Fig. A.5 (continued)
Graphic Analysis of Thomas' design process

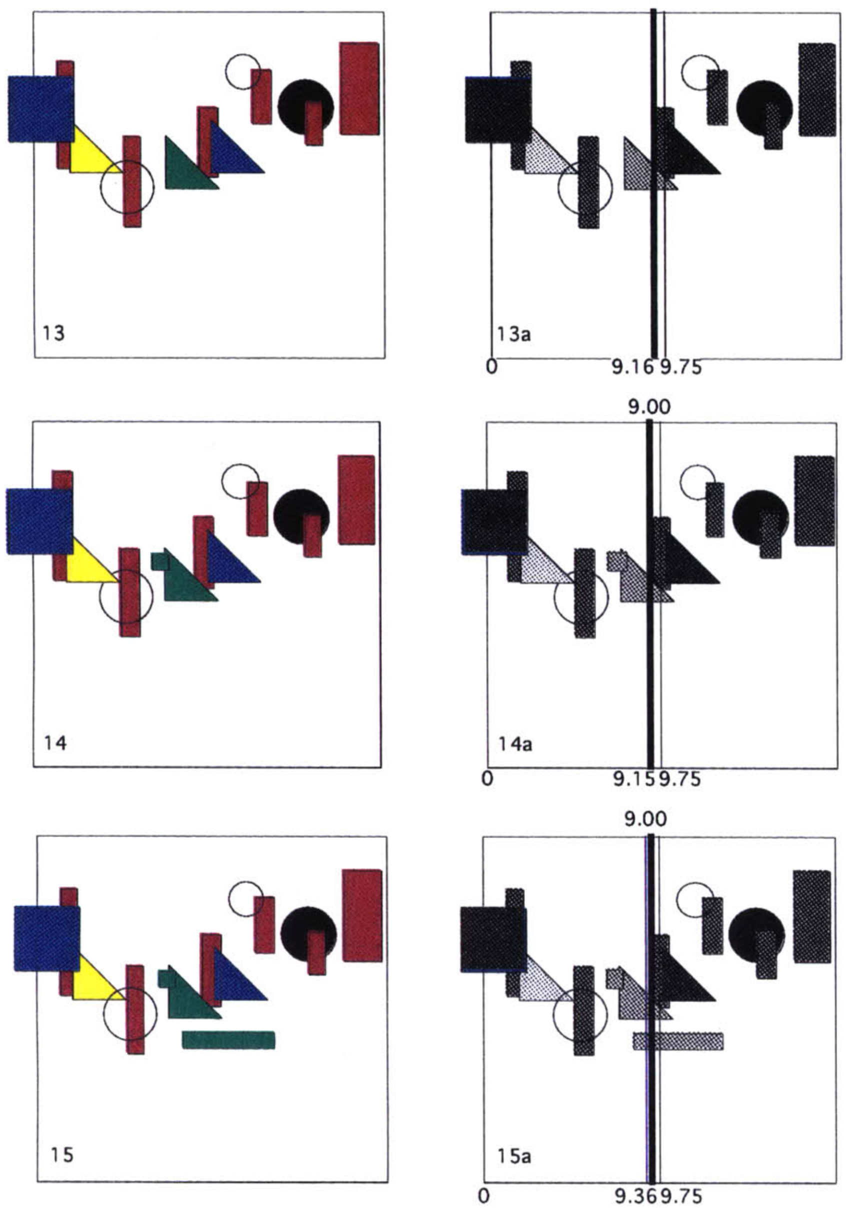


Fig. A.5 (continued)
Graphic Analysis of Thomas'
design process

APPENDIX A.4

Graphic and Verbal Protocol Analysis

Tables

TABLE A.I

Scheme of the Spoken Game with Abstract Elements"

(Issues)

Part	Designer	Activities	Rules	Issues
1	Designer A (THOMAS)	Design	Design Rule	How is the design rule different from the evaluation rule?
		Evaluate	Evaluation Rule	
	Designer B (DAN)	Evaluate	Evaluation Rule	Does B use the same evaluation rule as designer A?
2	Designer B (DAN)	Design	Design Rule	How is the design rule used different from the A's design rule? How is it different from the evaluation rule used by B in the first part of the experiment?
		Evaluation	Evaluation Rule	Is the rule the same used in the first part to evaluate A's design?
	Designer A (THOMAS)	Evaluation	Evaluation Rule	How is it different from the design and evaluation rules used in the first part?

TABLE A.II

Scheme of the "Spoken Game with Abstract Elements"

(Results and conclusions)

Part	Designer	Activities	Rules	conclusions
1	Designer A (THOMAS)	Design	Place the red elements from the left to the right, occasionally interrupt this procedure to start laying down the secondary elements, and then continue placing the red elements from the left to the right, with the exception of the last one	It is more efficient than the evaluation rule
		Evaluate	*'First I am going to repeat those vertical things in that direction. (...) (then) some smaller elements. All for the sake of diversity. Small elements of another color and size.'*	
	Designer B (DAN)	Evaluate	*'It seems that the reds are structural, and the other elements are, somehow, secondary elements.'*	His evaluation rule is different from designer's A one, due to the different way he interpreted the problem
2	Designer B (DAN)	Design	First, to 'frame' the composition by laying down the elements on the extremes, then to place the red elements, 'the frame', from the right to the left, and finally to place the secondary elements, 'the intuitive moves'	It is different from A's design rule It is less efficient than the evaluation rule he used by in the first part of the experiment?
		Evaluation	same as in the first part	Yes
	Designer A (THOMAS)	Evaluation	same as in the first part	It is more efficient than the design rule he used in the first part

Table A.III

Setting - Parameters and Values

Parameters	Values
Shapes (6)	circle square left triangle right triangle horizontal rectangle vertical rectangle
Sizes (27)	Between 5 and 8 different sizes for each shape 8 for the vertical rectangles 8 for the horizontal rectangles 6 for the circles 5 for the triangles
Colors (6)	black white red green yellow blue
Position	
Number of different elements: 240	

Table A.IV

Number of values used for each parameter

Parameters	Thomas	Dan	Max.
Total number of colors	6	6	6
Total number of shapes	5	5	6
Total number of sizes	8	8	27
Total Number of elements	15	11	240

Table A.V - Color Repetition

Color	Thomas	Dan
red	6	6
green	3	1
blue	2	1
white	2	1
yellow	1	1
black	1	1

Table A.VI

Shape Repetition

Shape	Thomas	Dan
rectangles	7	6
triangles	3	2
circles	3	2
squares	2	1

Table A.VII

Color/Shape Repetition

Color/Shape	Thomas	Dan
vertical red rectangles	6	2
horizontal red rectangles		4
black circle	1	1(smaller)
blue square	1	1(smaller)
green triangle	1	1(smaller)
yellow triangle	1	1(same size)
empty circles	2	
green rectangle	1	
blue triangle	1	
green square	1	

Table A.VIII

Color/Shape/Size Repetition

Thomas			
Number	Shape	Color	Size
6	vertical rectangles	same color	different sizes
3	triangles	different colors	same size
3	circles	2 with the same color (black or white)	2 with the same size
2	squares	different colors (a big and a small)	different sizes
1	horizontal rectangle	green	
Dan			
Number	Shape	Color	Size
4	horizontal rectangles	same color	different sizes
2	vertical rectangles	same color	different sizes
2	triangles	different colors	different sizes
2	circles	different colors	different sizes
1	square	blue	

Table A.IX

Rules

(from the more abstract to the more specific)

Thomas	**Dan**
Rules	
Do not connect the two sides with a straight line	connect
A framework (the majority-more repetition) bigger(stated but not respected) and an infill (the minorities-more variety) smaller(stated but not respected)	X
Make a clear distinction between the framework and the infill	even clearer
The framework is established by elements of the same shape and color and varying size	X
The framework is built with red elements	X
The framework is built with vertical elements	X
The framework is built with red vertical elements	horizontal also
The infill is built with elements of different color	X
Uses all the colors	X
Uses at least one of each kind of shape <u>except</u> right triangles	X
All the red elements are rectangles (color and shape repeated)	X
All the rectangles are red, <u>except</u> one (shape repeated and color repeated)	there is no exception
All the elements are different	X
All the triangular elements have the same size and different colors (the shape and size is repeated)	all the triangular elements are different
There are green elements of each shape <u>except</u> circle (the color is repeated)	only one green element
The circles are either black or white	X
Positioning rules: - Big blue square on the left - Big circle on the right - White circles in the middle - Green elements in the middle	 on the left
Rules about the rules:	X
A rule and then an exception to the rule. Repetition, and surprise (even this rule obeys to itself).	not so obvious
He started from bigger shapes to small ones	alternates

TABLE A.X

Values of the X Coordinate of the Reference Axes of Thomas' Design

Move	designed area axis	compositional axis (without w)	compositional axis (with w)	Drawing-board axis
move 2	3.63	3.45	3.45	9.75
move 3	5.73	5.13	5.13	9.75
move 4	7.23	6.40	6.40	9.75
move 5	7.23	5.80	6.43	9.75
move 6	7.23	6.57	7.22	9.75
move 7	6.03	4.82	4.89	9.75
move 8	9.00	7.82	7.83	9.75
move 9	9.00	8.84	7.83	9.75
move 10	9.00	8.84	7.83	9.75
move 11	9.00	8.84	9.18	9.75
move 12	9.00	8.96	9.21	9.75
move 13	9.00	8.90	9.16	9.75
move 14	9.00	8.56	9.35	9.75
move 15	9.00	8.73	9.56	9.75

APPENDIX A.5

Balance Formulas

I
Horizontal Visual Balance
Average Top Height formula

$$h_{ay} = \frac{y_1 x_1 + y_2 x_2 + \ldots + y_n x_n}{x_1 + x_2 + \ldots + x_n}$$

y_n- height of the top boundary of element n
x_n- width of the element n

II
Horizontal Visual Balance
Average Bottom Height Formula

$$h_{ay'} = \frac{y'_1 x_1 + y'_2 x_2 + \ldots + y'_n x_n}{x_1 + x_2 + \ldots + x_n}$$

y'_n- height of the bottom boundary of element n
x_n- width of element n

III
Horizontal Visual Balance
Average Height Formula

$$h_a = \frac{(y_1+y_1')x_1 + (y_2+y_2')x_2 + \ldots + (y_n+y_n')\,x_n}{2(x_1 + x_2 + \ldots + x_n)}$$

y_n- height of the bottom boundary of element n
y'_n- height of the bottom boundary of element n
x_n- width of element n

I V
Gray Index

$$y = 0.299\,R + 0.587\,G + 0.114\,B$$

y - White Index
R - Red
G - Green
B - Blue

V
Color Weight Index Formula

$$w = \frac{65535 - y}{65535}$$

w - Color Weighting Index
y - White Index

VI
Vertical Visual Balance Formula

$$x = \frac{(w_1 - w_b)^* A_1 D_1 + (w_2 - w_b)^* A_2 D_2 + \ldots + (w_n - w_b)^* A_n D_n}{(w_1 - w_b)^* A_1 + (w_2 - w_b)^* A_2 + \ldots + (w_n - w_b)^* A_n}$$

x - x coordinate of the compositional balance axis
$w_{1...b}$ - Color Weight Indexes of each shape color
w_b - Color Weight Indexes of the background
A - Area of the shape
D - Distance of the shape center to the origin
*(wn - wb) - Color weight of the shape relatively to the background if wn>wb
*(wb - wn) - Color weight of the shape relatively to the background if wb>wn

V

TABLE I
RGB and Color Weight Index Values for the Principal Colors

	Red	Green	Blue	Hue	Saturation	Brightness	w
White	65535	65535	65535	0	0	65535	0
Yellow	65535	65535	0	10922	65535	65535	0.114
Green	0	65535	0	21845	65535	65535	0.413
Cyan		65535	65535	32767	65535	65535	0.299
Blue	0	0	65535	43690	65535	65535	0.886
Magenta	65535		65535	54612	65535	65535	0.587
Red	65535	0	0	65535	65535	65535	0.701
Black	0	0	0	0	0	0	1

APPENDIX A.6

Calculus of the compositional axes of Thomas' design using the formulas developed

Calculus of the x Coordinate of the compositional axis of Thomas' design (without color weight indexes)

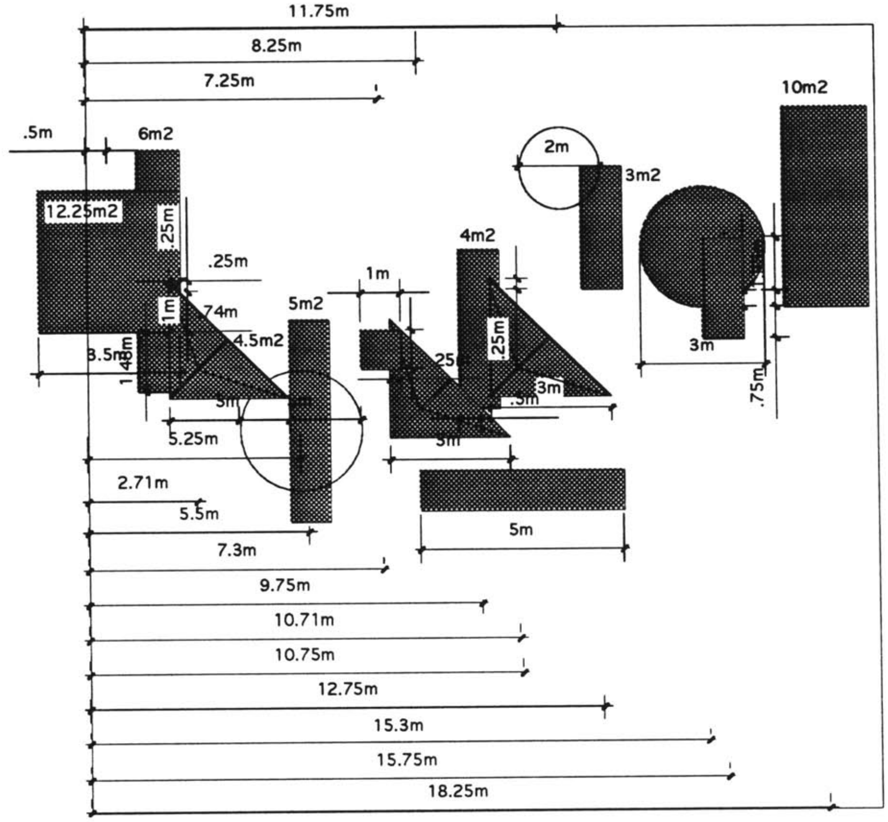


Figure A.4
Measurements of Thomas' design

After move 2

$$\frac{6.00 \times 1.75 + 5.00 \times 5.50}{6.00 + 5.00} = \frac{10.50 + 27.50}{11.00} = \frac{38.00}{11.00} = 3.45$$

After move 3

$$\frac{38.00 + 4.00 \times 9.750}{11.00 + 4.00} = \frac{38.0 + 39.00}{15.000} = \frac{77.00}{15.00} = 5.13$$

After move 4

$$\frac{6.00 \times 1.75 + 5.00 \times 5.5 + 4.00 \times 9.75 + 3.00 \times 12.75}{6.00 + 5.00 + 4.00 + 3.00} = \frac{10.50 + 27.5 + 39.00 + 38.50}{18.00} = \frac{115.50}{18.00} = 6.42$$

After move 5

$$\frac{(6.00 - 0.68) \times 1.75 + 4.50 \times 2.71 + 5.00 \times 5.50 + 4.00 \times 9.75 + 3.00 \times 12.75}{5.32 + 4.50 + 5.00 + 4.00 + 3.00} = \frac{9.31 + 12.20 + 27.50 + 39.00 + 38.25}{21.82} = \frac{126.26}{21.82} = 5.79$$

After move 6

$$\frac{(6.00 - 0.68) \times 1.75 + 4.5 \times 2.71 + 5.00 \times 5.50 + (4.00-0.63) \times 9.75 + 4.50 \times 10.75 + 3.00 \times 12.75}{5.32 + 4.5 + 5 + 3.38 + 4.5 + 3} =$$

$$\frac{9.31 + 12.20 + 27.50 + 32.90 + 48.38 + 38.50}{25.70} = \frac{168.79}{25.70} = 6.57$$

After move 7

$$\frac{12.25 \times 0.50 + (6.00 - 3.90) \times 1.75 + (4.50 - 0.68) \times 2.71 + 5.00 \times 5.50 + (4.00 - 0.625) \times 9.75 + 4.50 \times 10.75 + 3.00 \times 12.75}{12.25 + 2.10 + 4.19 + 5 + 3.38 + 4.5 + 3} =$$

$$\frac{6.13 + 3.68 + 10.35 + 27.50 + 32.91 + 48.38 + 38.50}{34.73} = \frac{167.45}{34.73} = 4.82$$

After move 8

$$\frac{167.45 + 182.50}{34.73 + 10.00} = \frac{349.95}{44.73} = 7.82$$

After move 11

$$\frac{349.95 + 3.14 \times (1.50 \times 1.50) + 15.30}{44.73 + 7.07} = \frac{349.95 + 108.09}{51.80} = \frac{458.04}{51.80} = 8.84$$

After move 12

$$\frac{349.95 + (7.07 - 1.73)\ 15.30 + 2.5 \times 15.75}{44.73 + 5.34 + 2.5} = \frac{349.95 + 81.76 + 39.38}{52.57} = \frac{471.09}{52.57} = 8.96$$

After move 13

$$\frac{471.09 + 4.50 \times 8.25}{52.57 + 4.5} = \frac{508.22}{57.07} = 8.90$$

After move 14

$$\frac{419.04 + (4.00 - 0.25) \times 9.75 + (4.50 - 0.25) \times 8.25 + 7.25}{48.47 + 3.75 + 4.25 + 1.00} = \frac{419.04 + 30.47 + 35.06 + 7.25}{57.47} = \frac{508.37}{57.47} = 8.56$$

After move 15

$$\frac{491.82 + 5.00 \times 10.7}{57.47 + 5.00} = \frac{491.82 + 53.55}{62.47} = 8.73$$

Calculus of the x Coordinate of the compositional axis of Thomas' design (with color weight indexes)

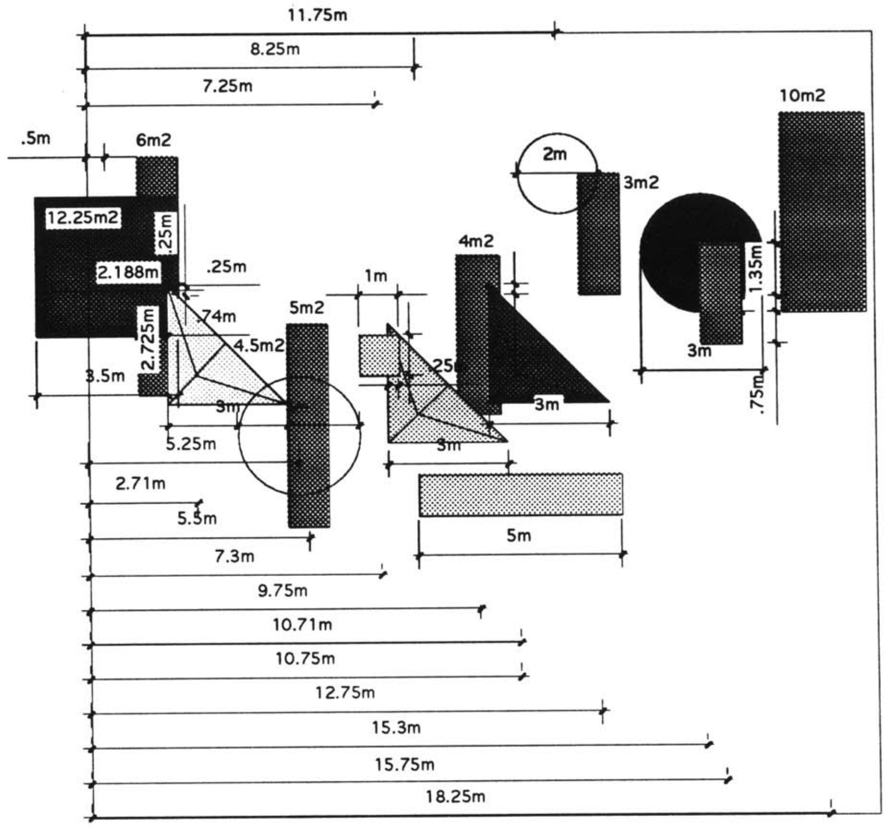


Figure A.7
Measurements of Thomas' design

After move 2

$$\frac{0.70 \times 6.00 \times 1.75 + 0.70 \times 5.00 \times 5.50}{0.70 \times 6.00 + 0.70 \times 5.00} = \frac{7.35 + 19.25}{4.20 + 3.50} = \frac{26.60}{7.70} = 3.45$$

After move 3

$$\frac{26.60 + 27.30}{7.70 + 2.80} = \frac{53.90}{10.50} = 5.13$$

After move 4

$$\frac{0.70 \times 6.00 \times 1.75 + 0.70 \times 5.00 \times 5.50 + 0.70 \times 4.00 \times 9.75 + 0.70 \times 3.00 \times 12.75}{0.70 \times 6.00 + 0.70 \times 5.00 + 0.70 \times 4.00 + 0.70 \times 3.00} =$$

$$\frac{7.35 + 19.25 + 27.30 + 26.78}{4.20 + 3.50 + 2.80 + 2.10} = \frac{80.68}{12.60} = 6.40$$

After move 5

$$\frac{0.70 \times (6 - 0.68) \times 1.75 + 0.11 \times 4.50 \times 2.71 + 0.70 \times 5.00 \times 5.50 + 0.70 \times 4.00 \times 9.75 + 0.70 \times 3.00 \times 12.75}{0.70 \times 5.32 + 0.11 \times 4.50 + 0.70 \times 5.00 + 0.70 \times 4.00 + 0.70 \times 3.00} =$$

$$\frac{6.52 + 1.34 + 19.25 + 27.30 + 26.78}{3.72 + 0.50 + 3.50 + 2.80 + 2.10} = \frac{81.19}{12.63} = 6.43$$

After move 6

$$\frac{0.70 \times (6.00 - 0.68) \times 1.75 + 0.11 \times 4.50 \times 2.71 + 0.70 \times 5.00 \times 5.50 + 0.70 \times (4.00\text{-}0.63) \times 9.75 + 0.89 \times 4.50 \times 10.75 + 0.70 \times 3.00 \times 12.75}{0.70 \times 5.32 + 0.11 \times 4.50 + 0.70 \times 5.00 + 0.70 \times 3.38 + 0.89 \times 4.50 + 0.70 \times 3.00} =$$

$$\frac{6.52 + 1.34 + 19.25 + 23.00 + 40.15 + 26.78}{3.72 + 0.50 + 3.50 + 2.37 + 4.01 + 2.10} = \frac{117.04}{16.20} = 7.22$$

After move 7

$$\frac{0.89 \times 12.25 \times 0.50 + 0.70 \times (6.00 - 3.90) \times 1.75 + 0.11 \times (4.50 - 0.68) \times 2.71 + 0.70 \times 5.00 \times 5.50 + +0.70 \times (4\text{-}0.63) \times 9.75}{0.89 \times 12.25 + 0.70 \times 2.10 + 0.11 \times 4.19 + 0.70 \times 5.000 + 0.70 \times 3.38}$$

$$\frac{+ 0.89 \times 4.50 \times 10.75 + 0.70 \times 3.00 \times 12.75}{+ 0.89 \times 4.50 + 0.70 \times 3.0} =$$

$$\frac{5.45 + 2.57 + 1.14 + 19.25 + 23.00 + 43.05 + 26.78}{10.90 + 1.47 + 0.46 + 3.50 + 2.37 + 4.01 + 2.10} = \frac{121.24}{24.81} = 4.89$$

After move 8

$$\frac{121.24 + 0.70 \times 182.50}{24.81 + 0.70 \times 10.00} = \frac{248.99}{31.81} = 7.83$$

After move 11

$$\frac{248.99 + 1.00 \times 3.14 \times (1.50 \times 1.50) \times 15.30}{31.81 + 1 \times 7.07} = \frac{248.99 + 108.09}{38.88} = \frac{357.08}{38.88} = 9.18$$

After move 12

$$\frac{248.99 + 1.00 \times (7.07 - 1.73) \times 15.30 + 0.70 \times 2.50 \times 15.75}{31.81 + 1.00 \times 5.34 + 0.70 \times 2.50} = \frac{248.99 + 81.70 + 27.56}{31.81 + 5.34 + 1.75} = \frac{358.25}{38.90} = 9.21$$

After move 13

$$\frac{330.95 + 0.70 \times (4\text{-}.25) \times 9.75 + 0.41 \times 4.50 \times 8.25}{36.10 + 0.70 \times 3.75 + 0.41 \times 4.50} = \frac{330.95 + 25.59 + 15.22}{36.10 + 2.63 + 1.85} = \frac{371.76}{40.58} = 9.16$$

After move 14

$$\frac{330.95 + 0.70 \times (4.00 - 0.25) \times 9.75 + 0.41 \times (4.50 - 0.25) \times 8.25 + 0.41 \times 7.25}{36.10 + 0.70 \times 3.75 + 0.41 \times 4.25 + 0.41 \times 1.00} = \frac{330.95 + 25.59 + 14.38 + 2.97}{36.10 + 2.63 + 1.74 + 0.41} = \frac{373.89}{40.88} = 9.15$$

After move 15

$$\frac{373.89 + 0.41 \times 5.00 \times 10.71}{40.88 + 0.28 \times 5.00} = \frac{382.42 + 21.96}{40.88 + 1.40} = \frac{373{,}89}{42.28} = 9.36$$

Appendix B

The results of the "Spoken Game With Abstract Elements"

Appendix B.1 - Graphic Protocol
Appendix B.2 - Verbal Protocol
Appendix B.3 - Graphic and Verbal Protocol Analyses—Graphics
Appendix B.4 - Graphic and Verbal Protocol Analyses—Tables
Appendix B.5 - Calculations
Appendix B.6 - Ana's Design Process—Rules and Search Tree

Appendix B.1

Graphic Protocol

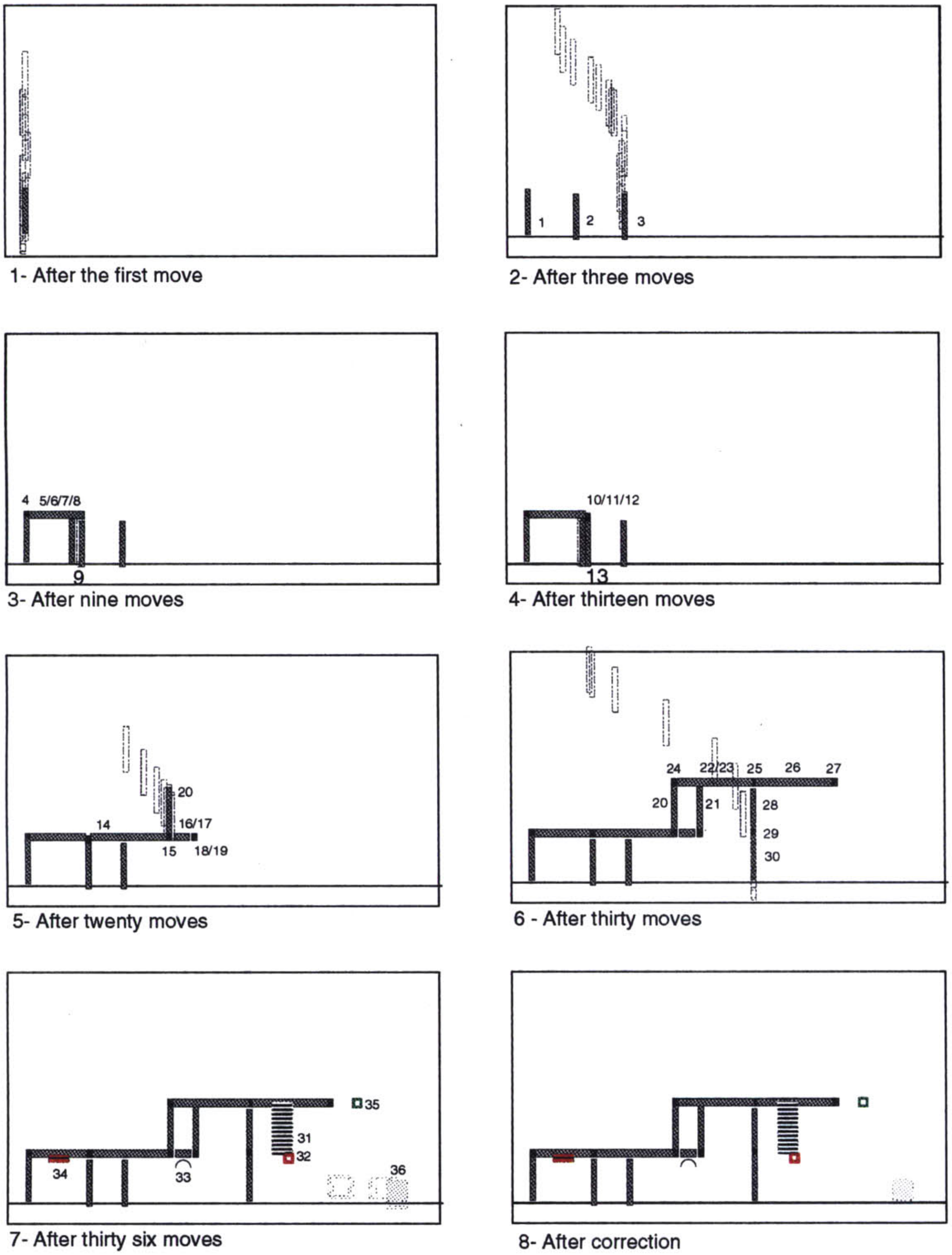


Fig. B.1
Thomas' design process—1st attempt

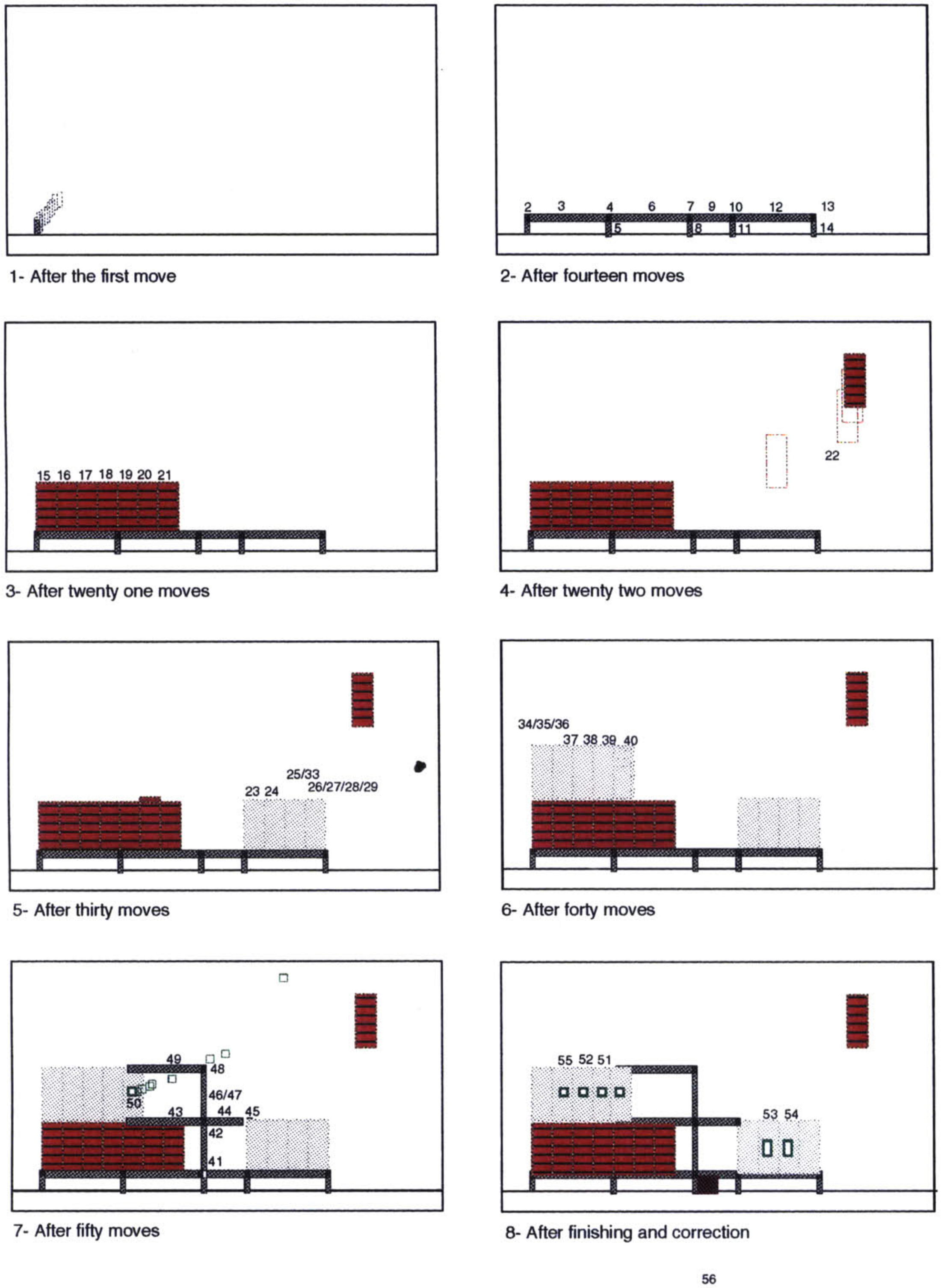
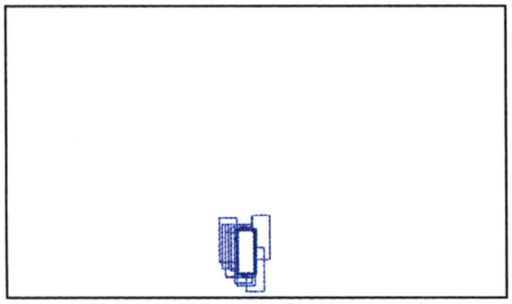
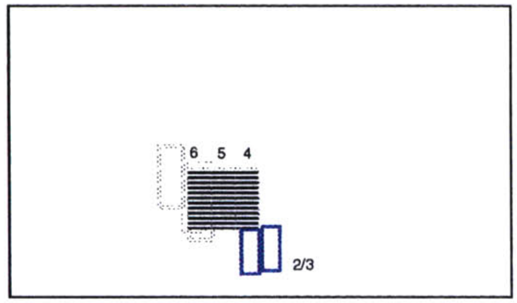


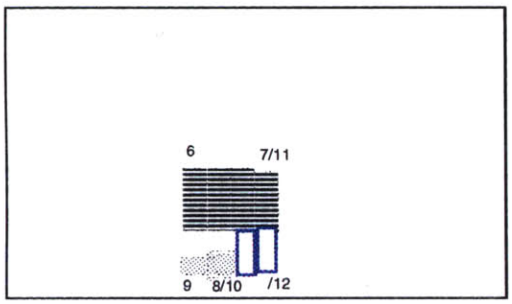
Fig. B.2
Thomas' design process



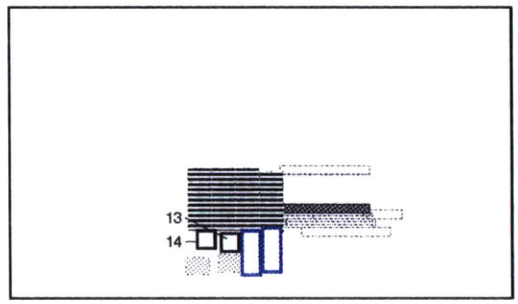
1- After the first move



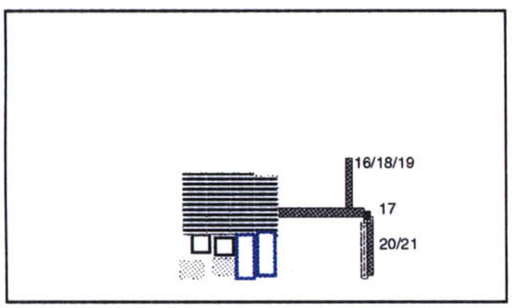
2- After six moves



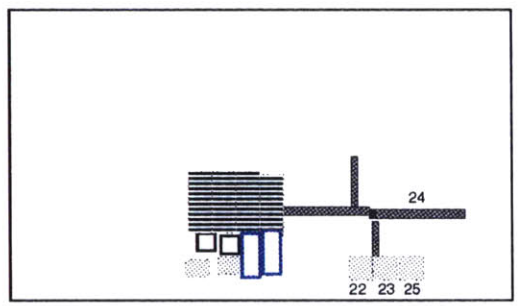
3- After twelve moves



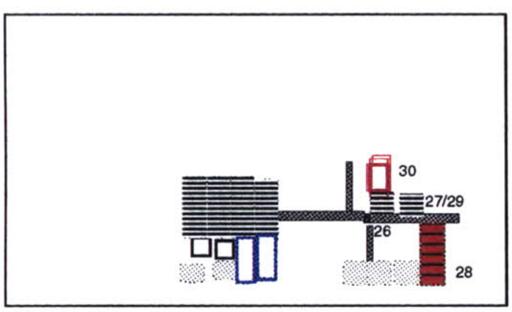
4- After fifteen moves



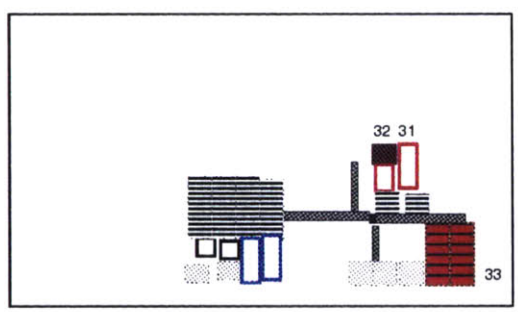
5- After twenty one moves



6- After twenty five moves

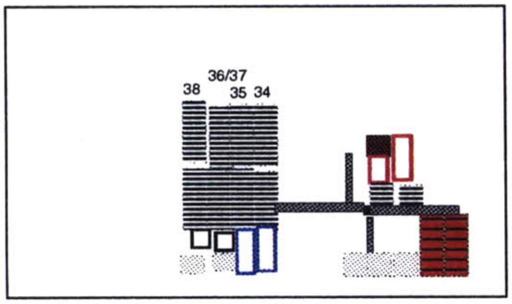


7- After thirty moves

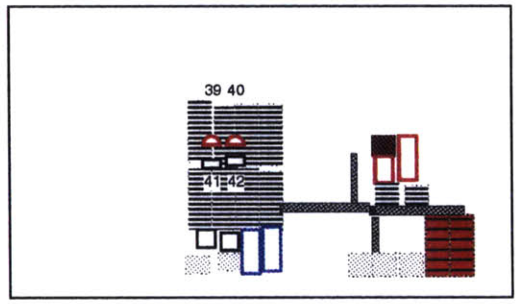


8- After thirty three moves

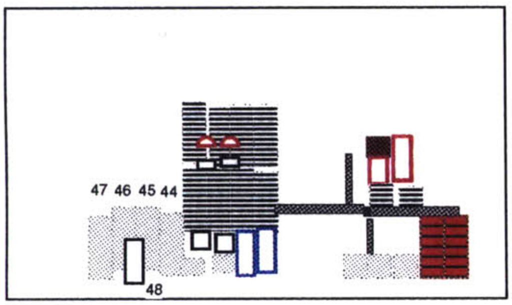
Fig. B.3
Joan's design process



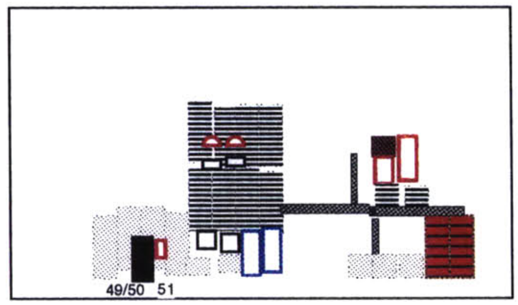
9- After thirty eight moves



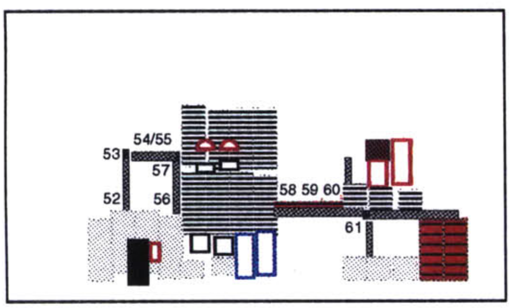
10- After forty two moves



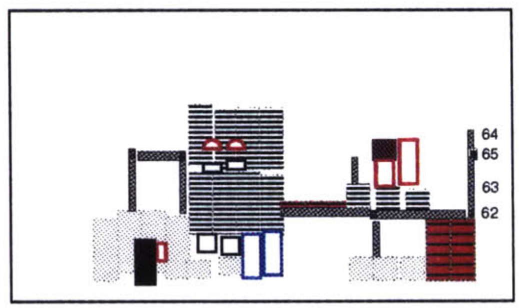
11- After forty eight moves



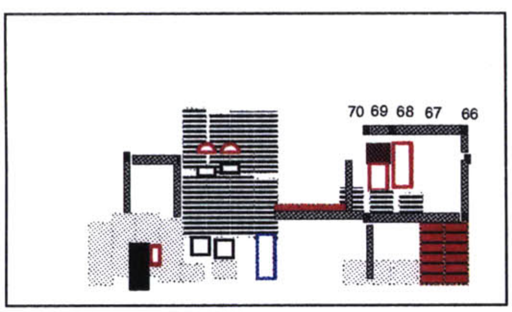
12- After fifty one moves



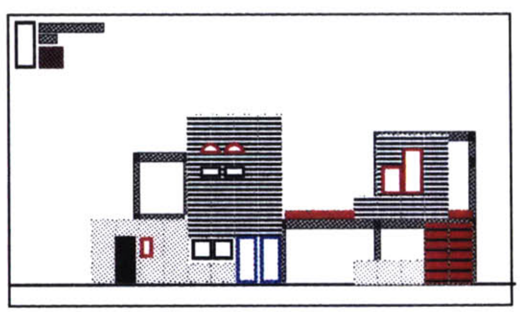
13- After sixty one moves



14- After sixty five moves



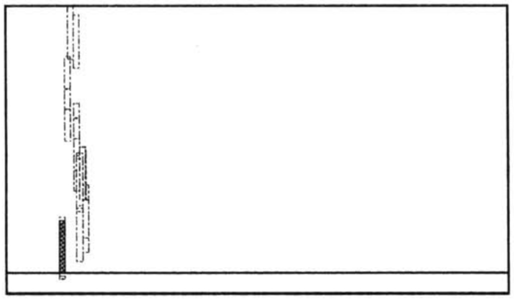
15- After sixty eight moves



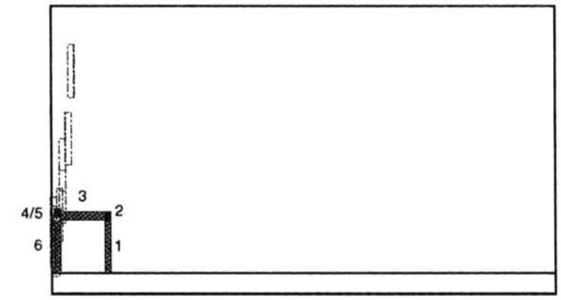
16- After correction

Fig. B.3

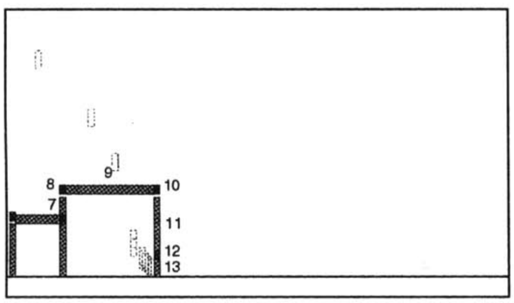
Joan's design process (continued



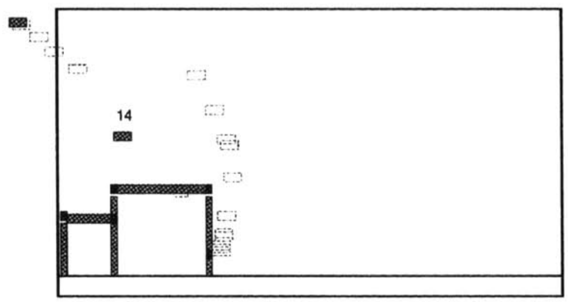
1- After the first move



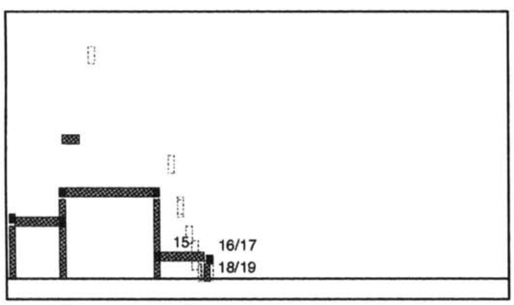
2- After six moves



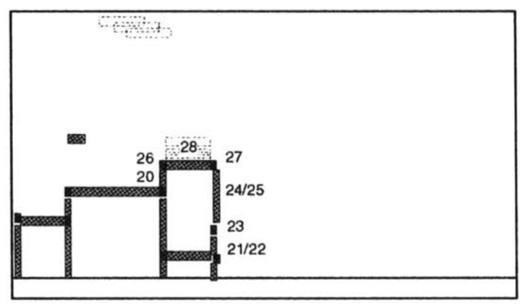
3- After thirteen moves



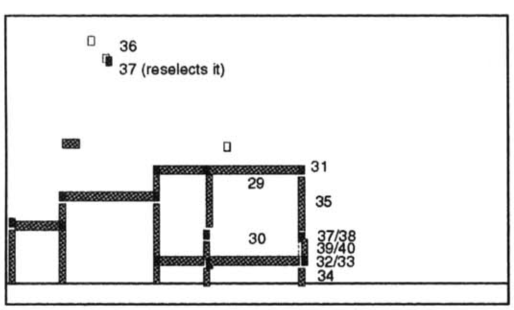
4- After fourteen moves (move fourteen)



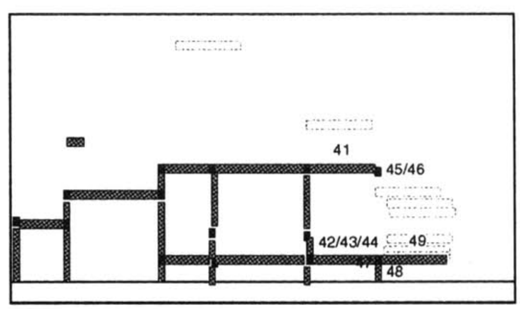
5- After nineteen moves



6- After twenty eight moves

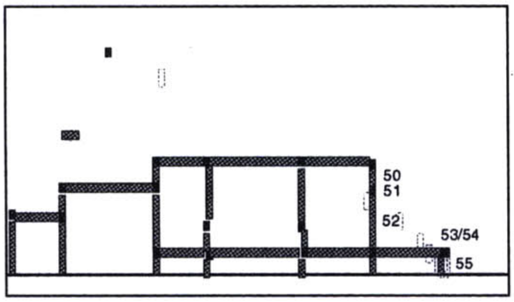


7- After forty moves

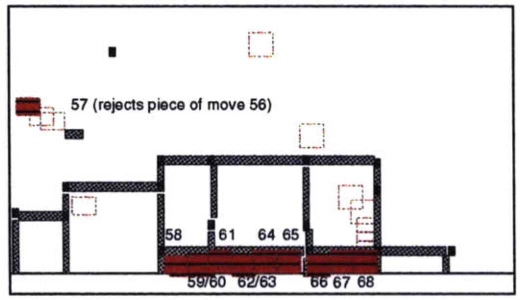


8- After forty nine moves

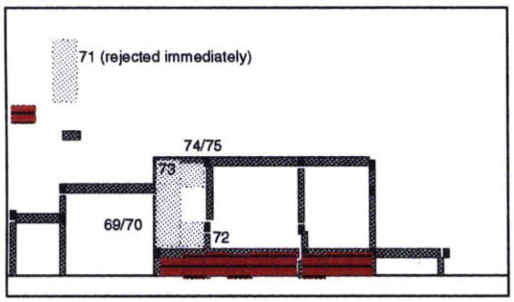
Fig. B.4
Wade's design process



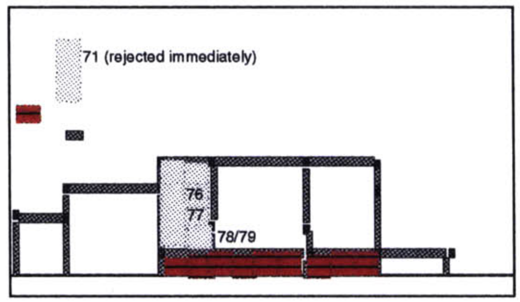
9 - After fifty five moves



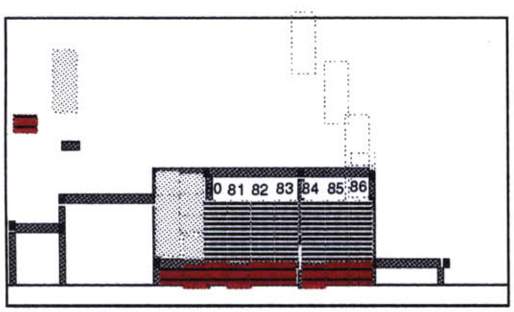
10- After sixty eight moves



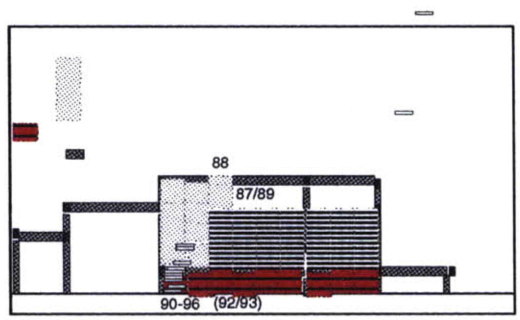
11 - After seventy five moves



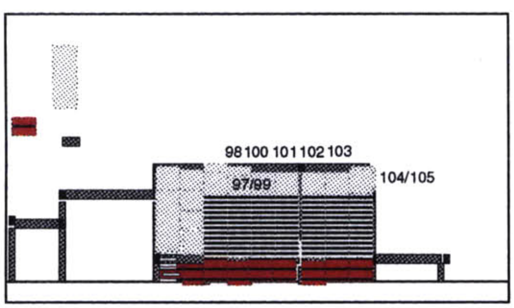
12 - After seventy nine move



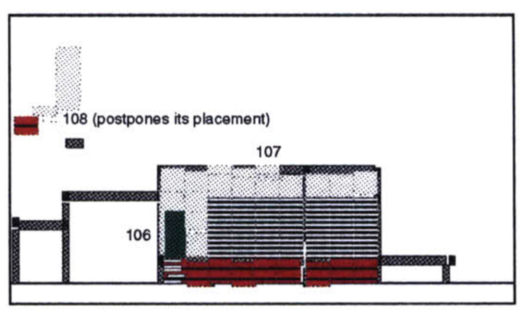
13 - After eighty six moves



14 - After ninety six moves

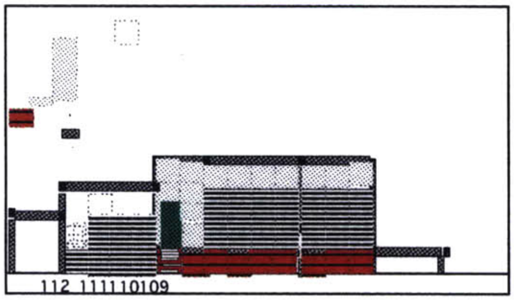


15 - After a hundred and five moves

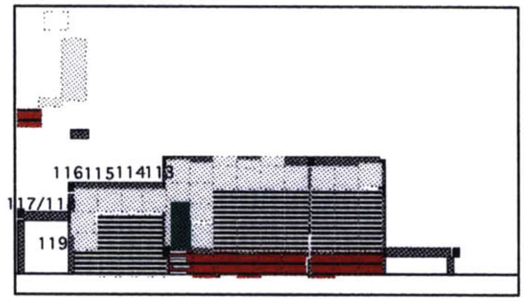


16 - After a hundred and eight moves

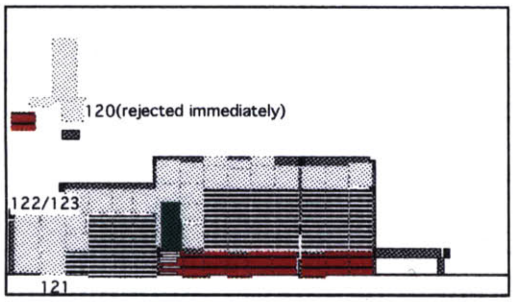
Fig. B.4
Wade's design process (continued)



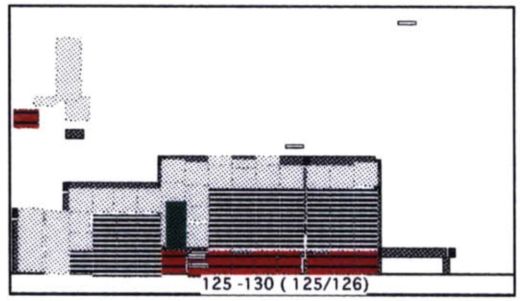
17 - After a hundred and twelve moves



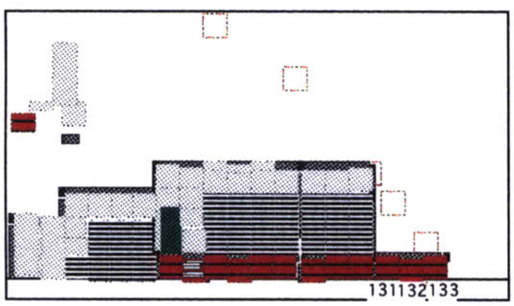
18 - After one hundred and nineteen moves



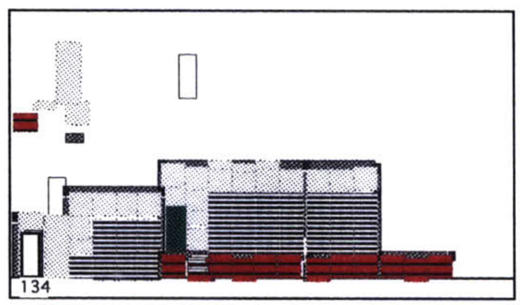
19 - After one hundred and twenty three moves



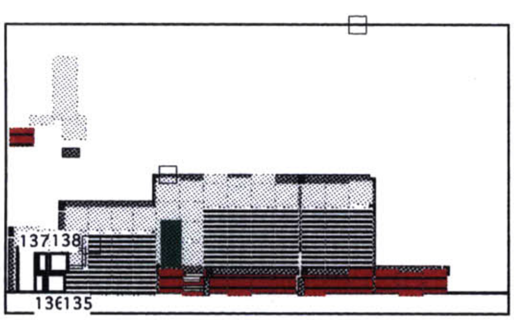
20 - After one hundred and thirty moves



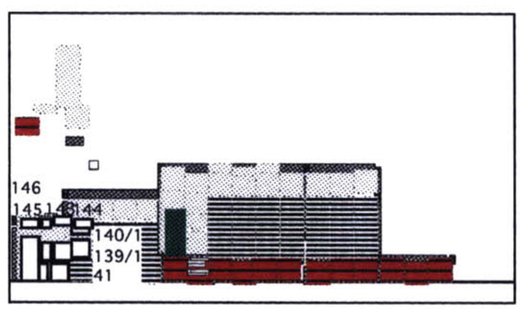
21- After one hundred and thirty three moves



22 - After one hundred and thirty four moves

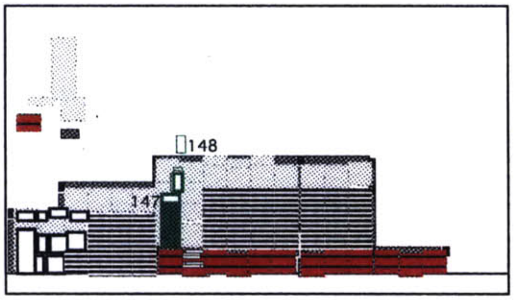


23 - After one hundred and thirty eight moves

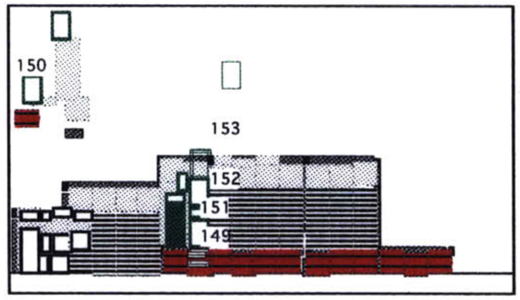


24 - After one hundred and forty six moves

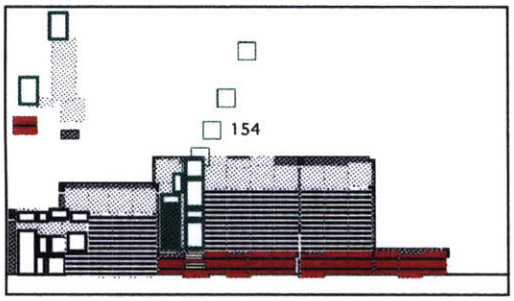
Fig. B.4
Wade's design process (continued)



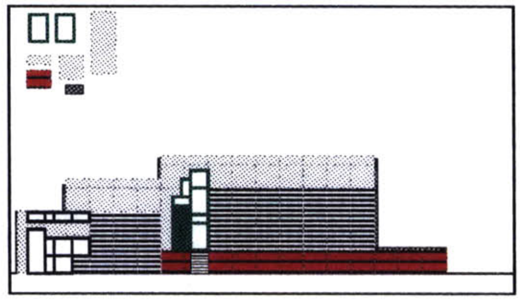
25 - After one hundred and forty eight moves



26 - After one hundred and fifty three moves

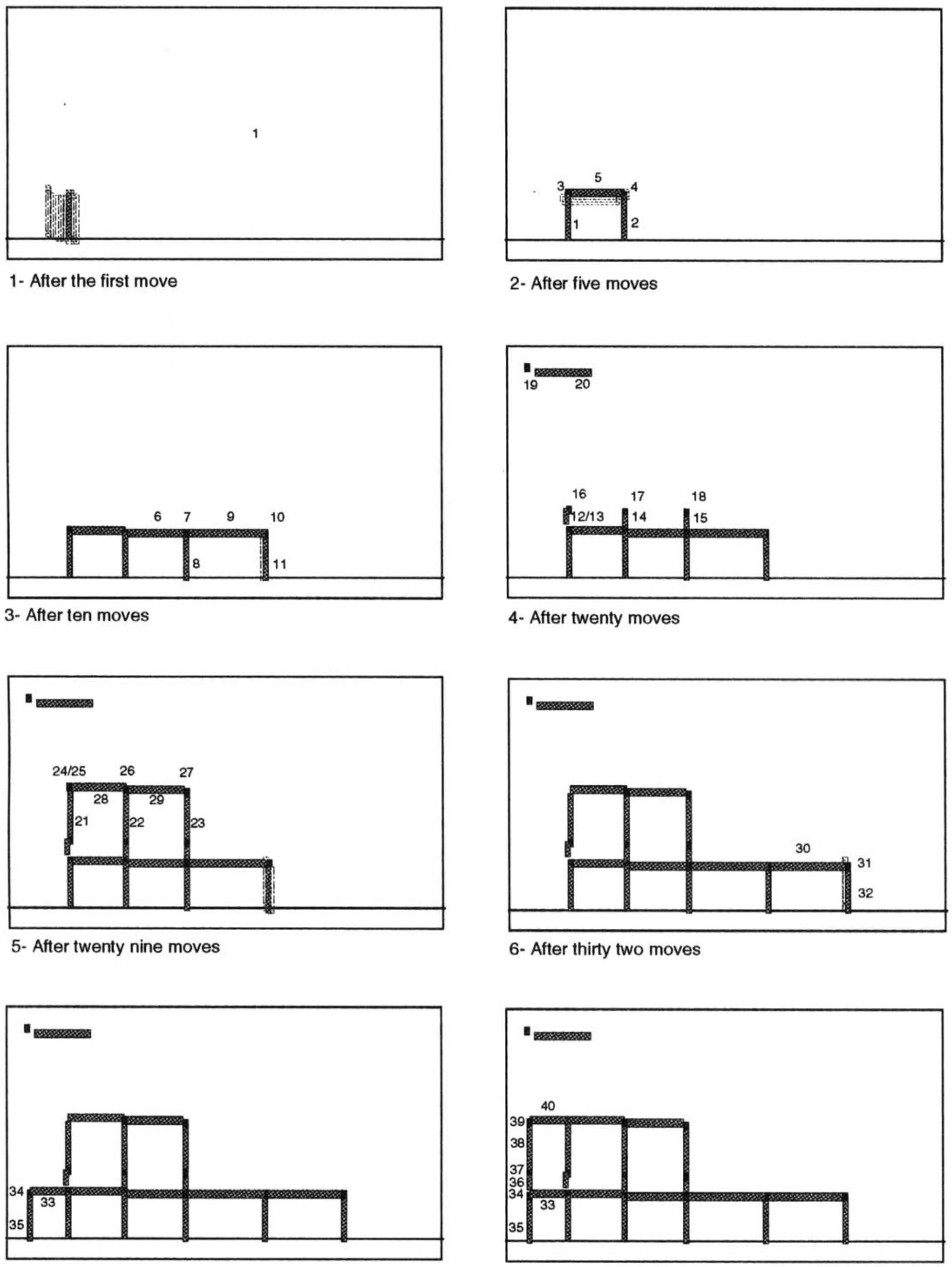


27 - After one hundred and fifty four moves



28 - After correction

Fig. B.4
Wade's design process (continued)



1- After the first move

2- After five moves

3- After ten moves

4- After twenty moves

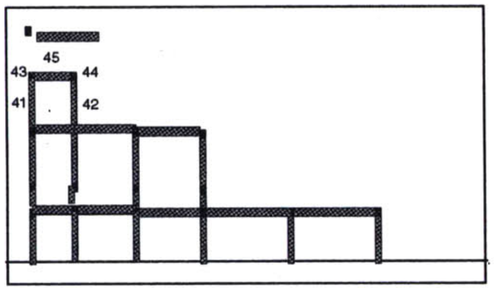
5- After twenty nine moves

6- After thirty two moves

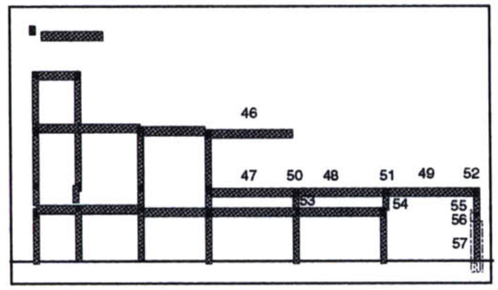
7- After thirty five moves

8- After forty moves

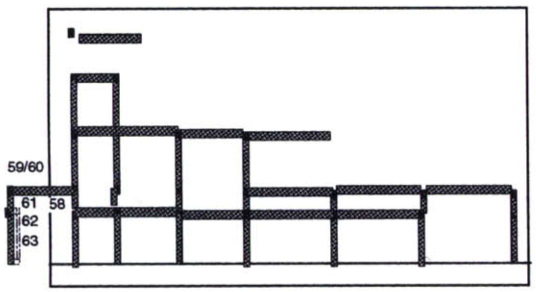
Fig. B.5
Taylor's design process (continued)



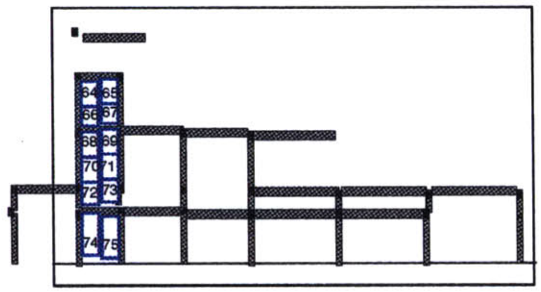
9 - After forty five moves



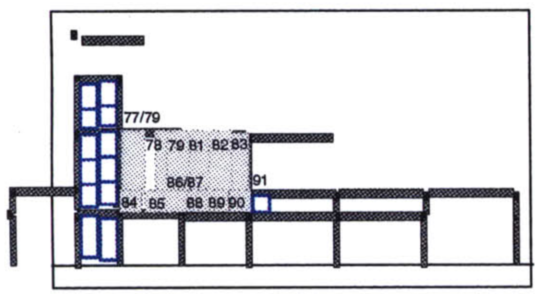
10 - After fifty seven moves



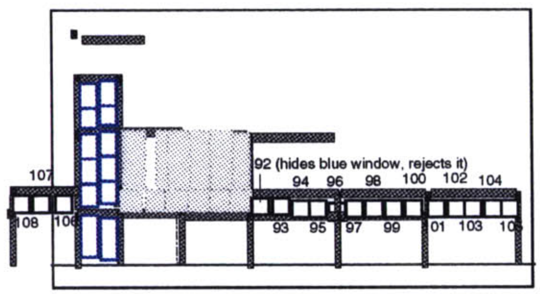
11 - After sixty three moves



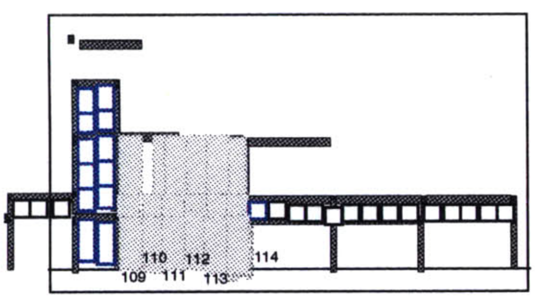
12 - After seventy five moves



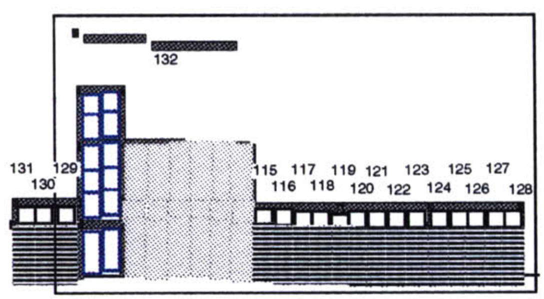
13 - After ninety and one moves



14 - After one hundred and seven moves

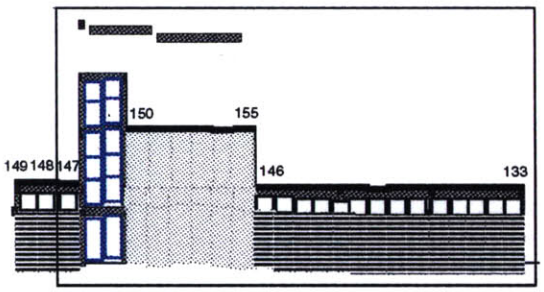


15 - After one hundred and fourteen moves

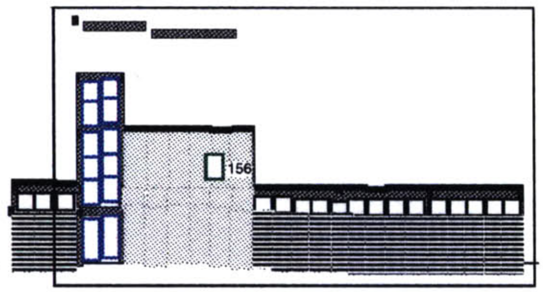


16 - After one hundred and thirty two moves

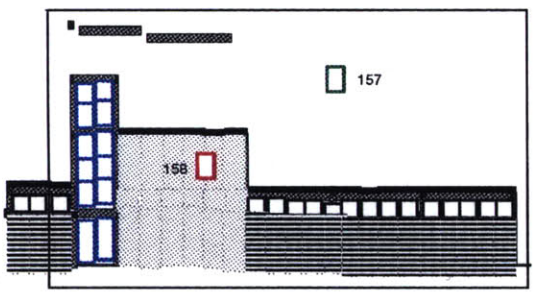
Fig. B.5
Taylor's design process (continued)



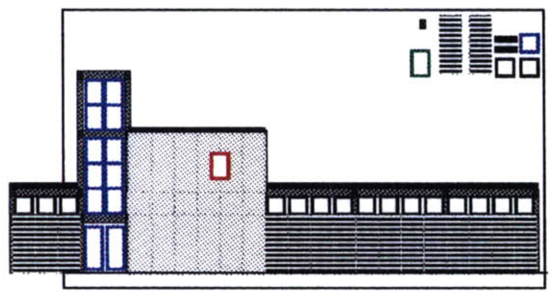
17 - After one hundred and fifty five moves



18 - After one hundred and fifty six moves



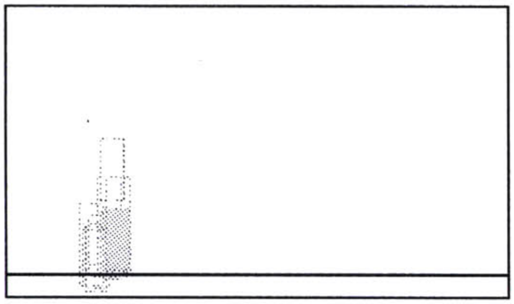
19 - After one hundred and fifty eight moves



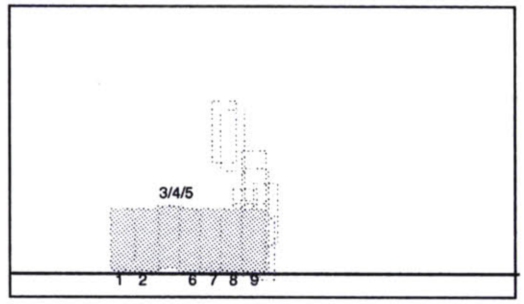
20 After correction

NOTE - The moves from move one hundred and thirteen through move one hundred and fifty one were not executed with the macro but with the copy and paste commands being the drawing saved after each goup of significant moves, as shown in frames 16 through 20.

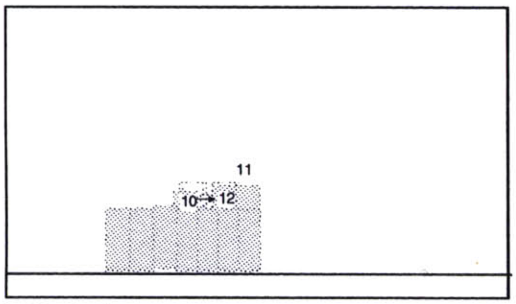
Fig. B.5
Taylor's design process (continued)



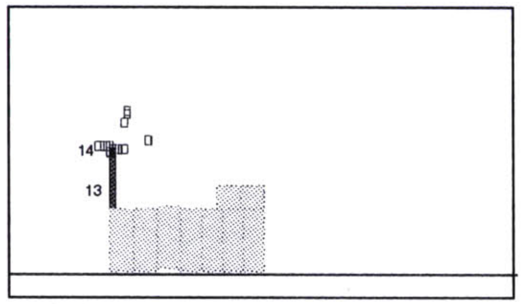
1- After the first move



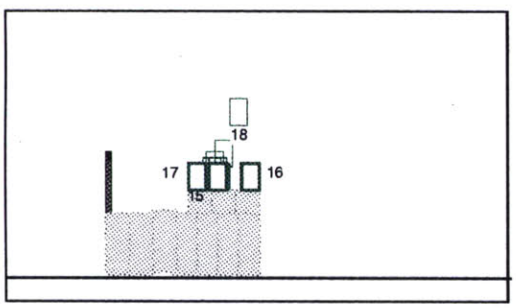
2- After nine moves



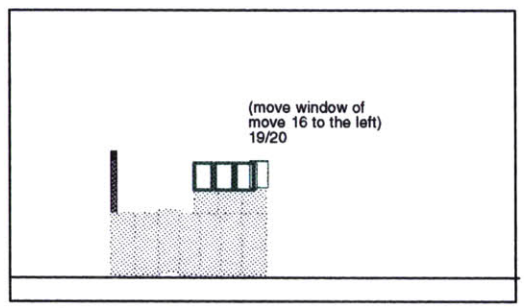
3- After twelve moves



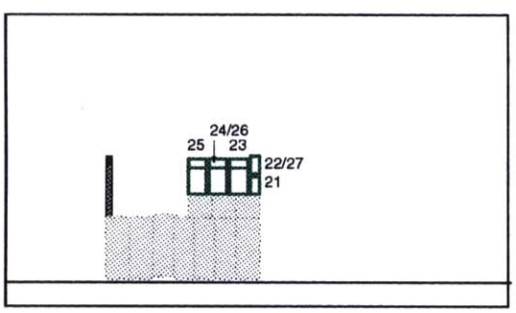
4- After fourteen moves



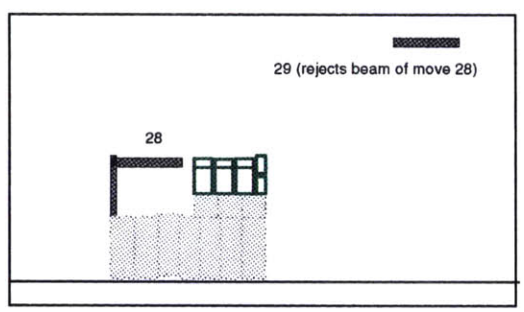
5- After eighteen moves



6- After twenty moves

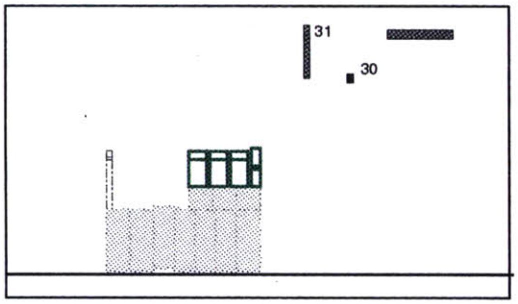


7- After twenty seven moves

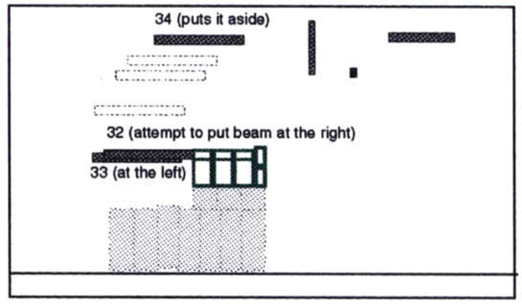


8- After twenty nine moves

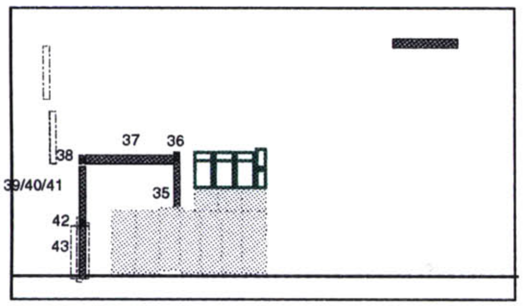
Fig. B.6
Salvatore's design process



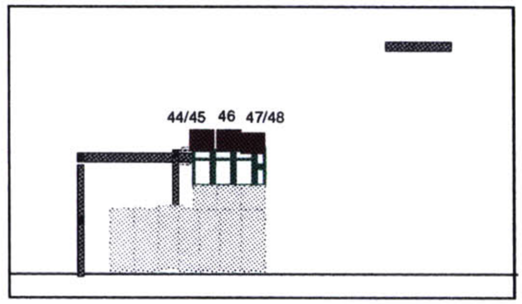
9- After thirty one moves



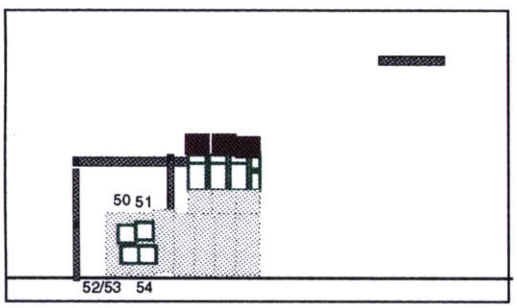
10- After forty five moves



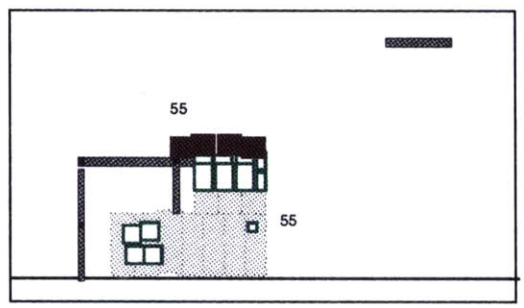
11- After forty three moves



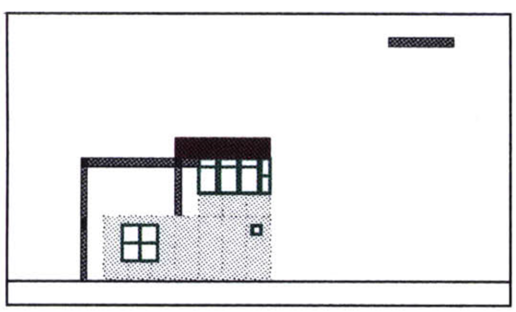
12 - After forty nine moves



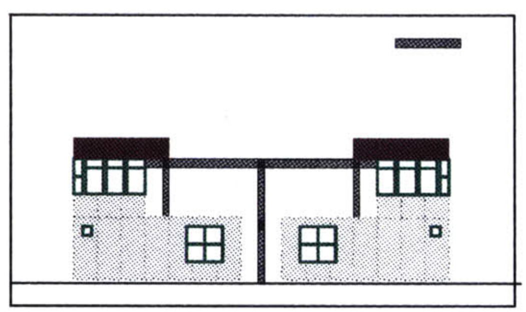
13 - After fifty four moves



14 - After fifty six moves



15 - After correction



16 - After mirror operation (see verbal protocol)

Fig. B.6
Salvatore's design process

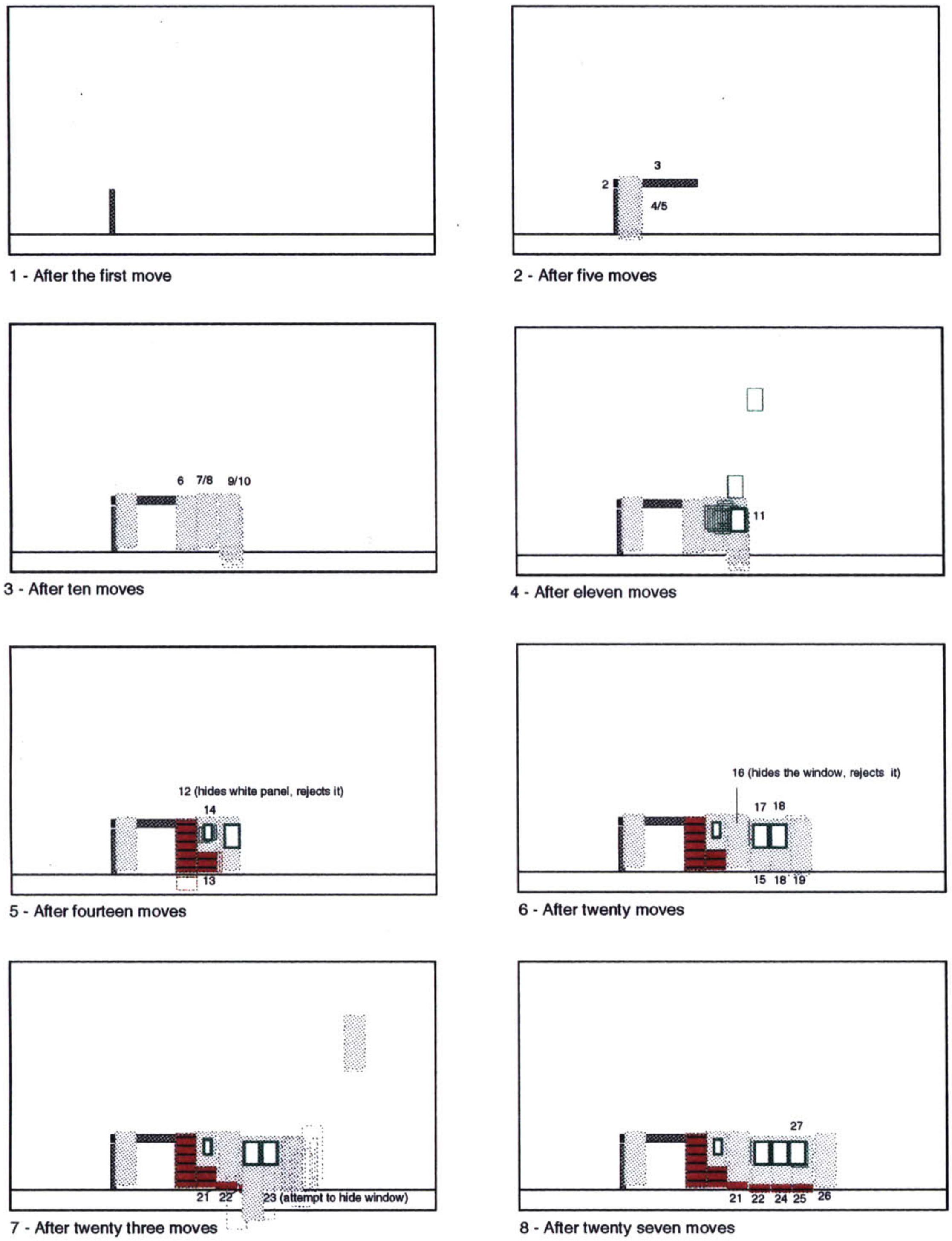
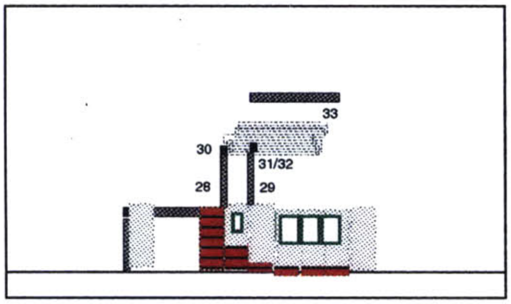
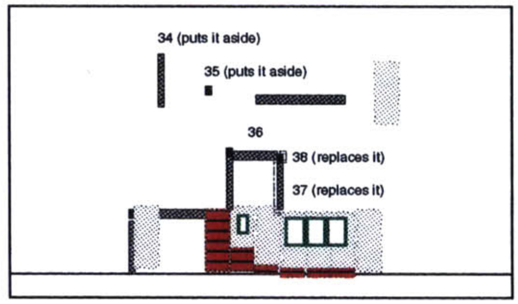


Fig. B.7

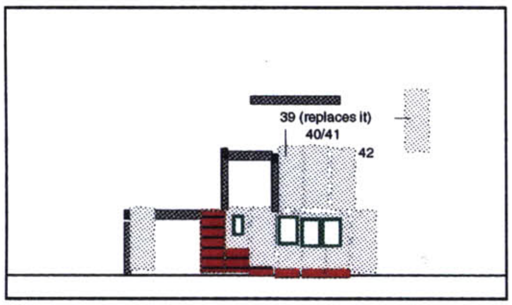
Ming's design process



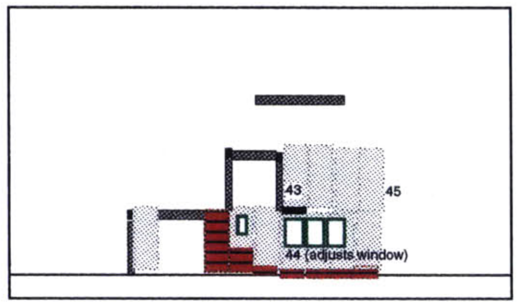
9 - After thirty three moves



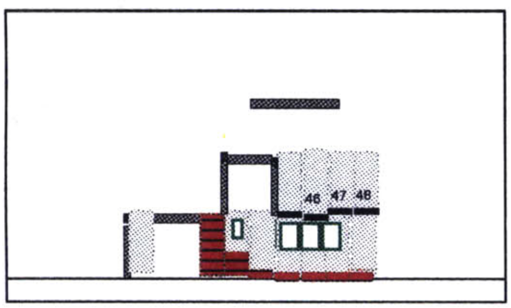
10 - After thirty eight moves



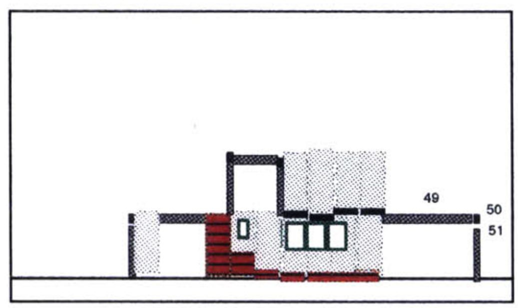
11 - After forty two moves



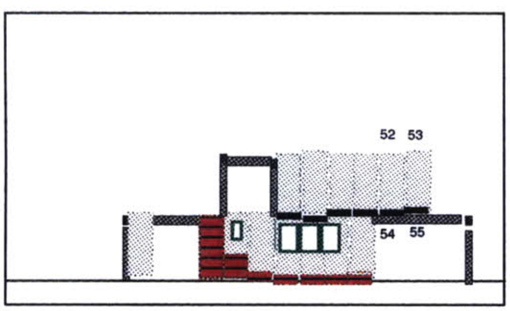
12 - After forty five moves



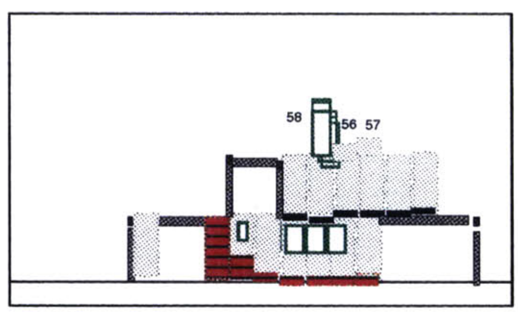
13 - After forty eight moves



14 - After fifty one moves

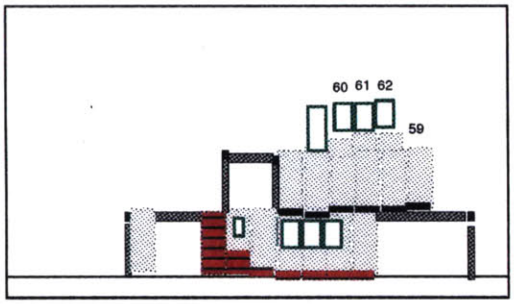


15 - After fifty five moves

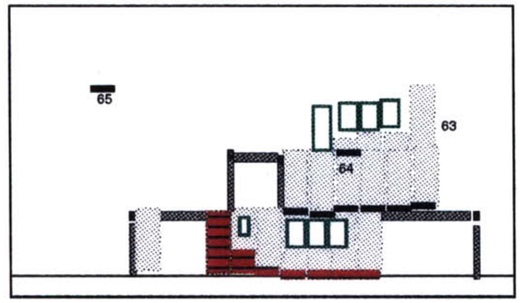


16 - After fifty seven moves

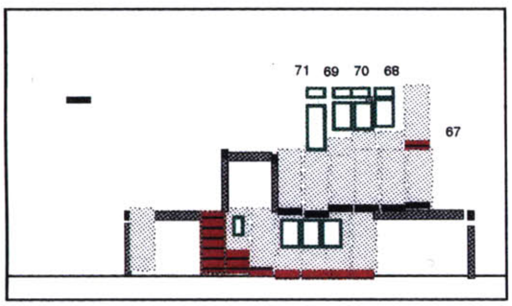
Fig. B.7
Ming's design process (continued)



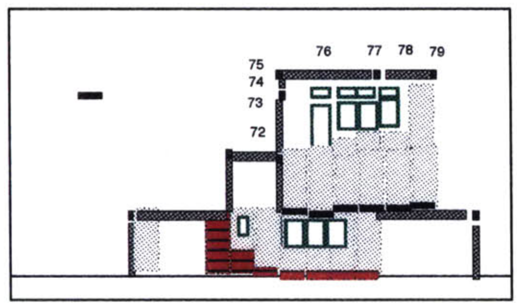
17 - After sixty two moves



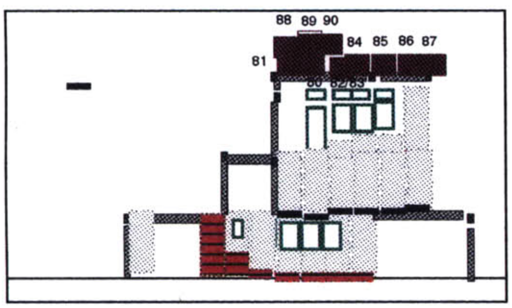
18 - After sixty five moves



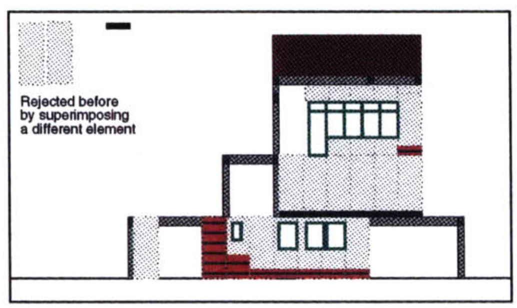
19 - After seventy one moves



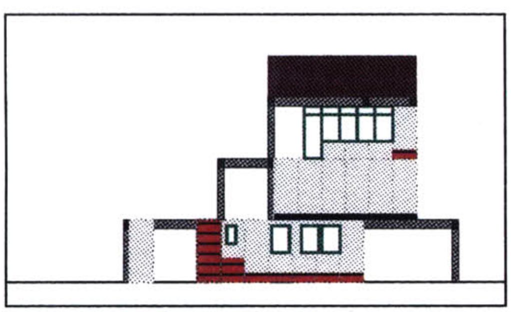
20 - After seventy nine moves



21 - After eighty seven moves



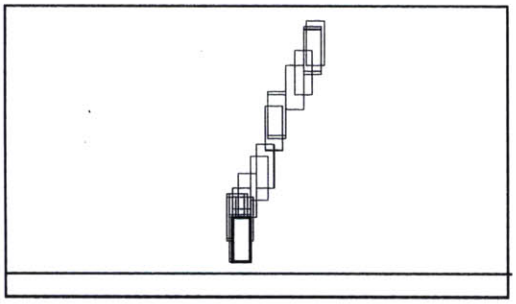
22 - After finishing and correction



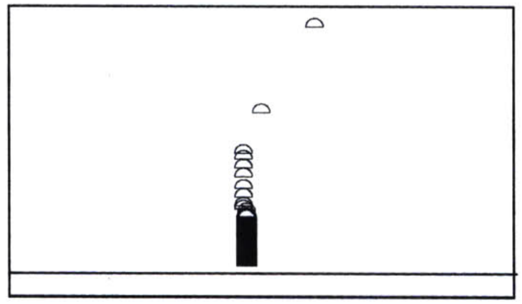
23 - The final solution if the misplacement of the elements had not required the design to go other way(move 74).

Fig. B.7

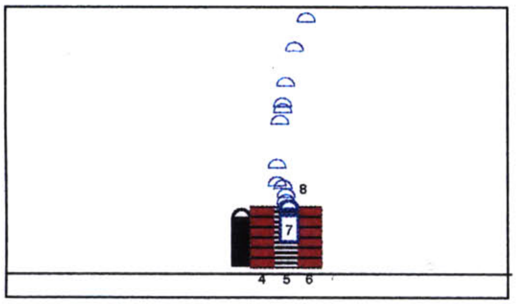
Ming's design process (continued)



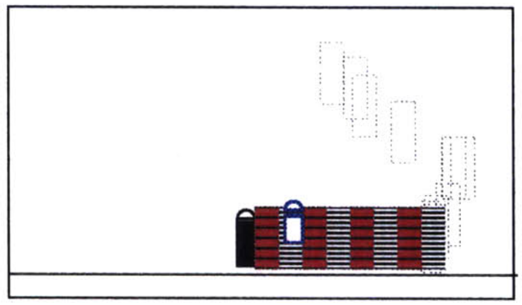
1 - After the first move



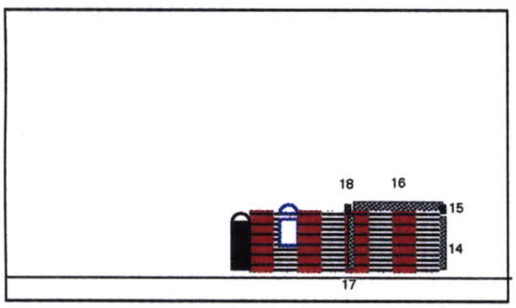
2- After three moves



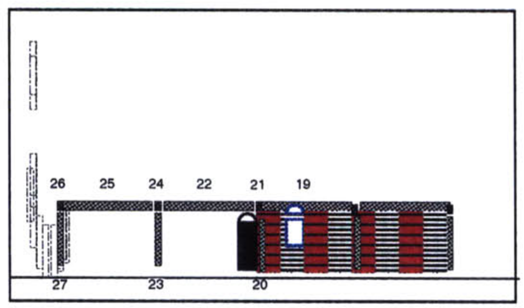
3- After eight moves



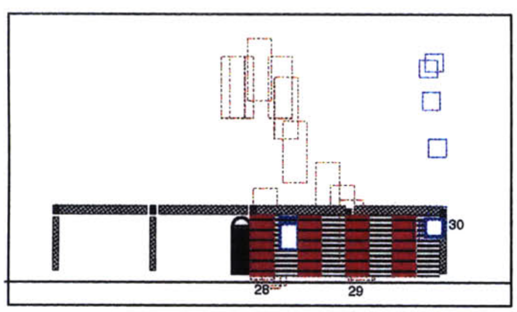
4 - After thirteen moves



5 - After seventeen moves



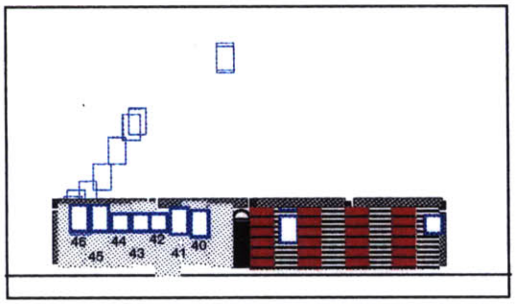
6- After twenty seven moves



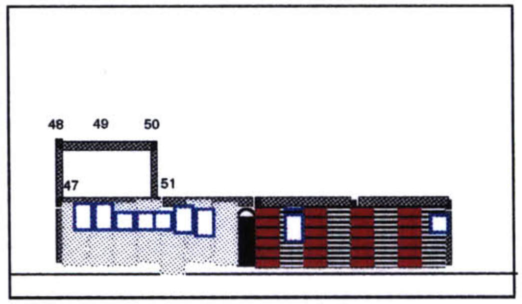
7- After thirty moves

8- After sixty moves

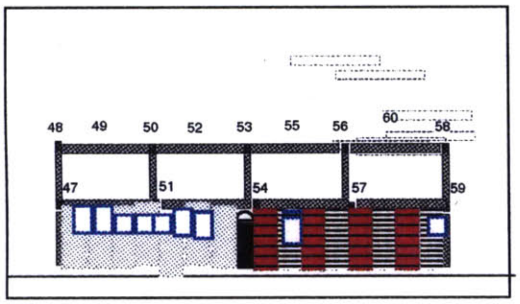
Fig. B.8
Pedro's design process



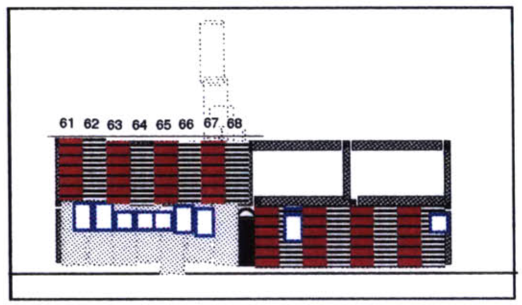
9 - After forty six moves



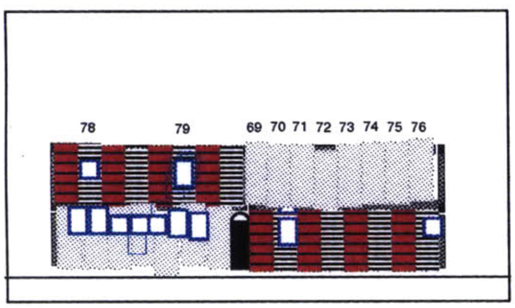
10 - After fifty one moves



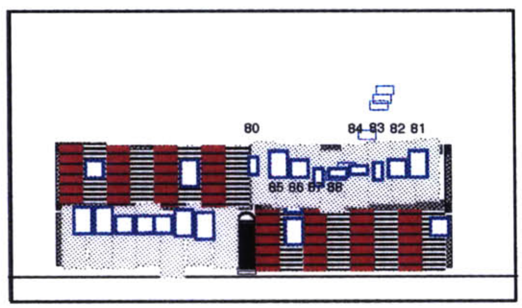
11 - After sixty moves



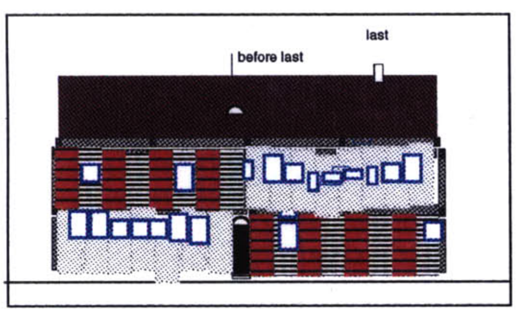
12 - After sixty eight moves



13 - After seventy nine moves



14 - After eighty eight moves



15 - After roof

16 - After correction

Fig. B.8
Pedro's design process (continued)

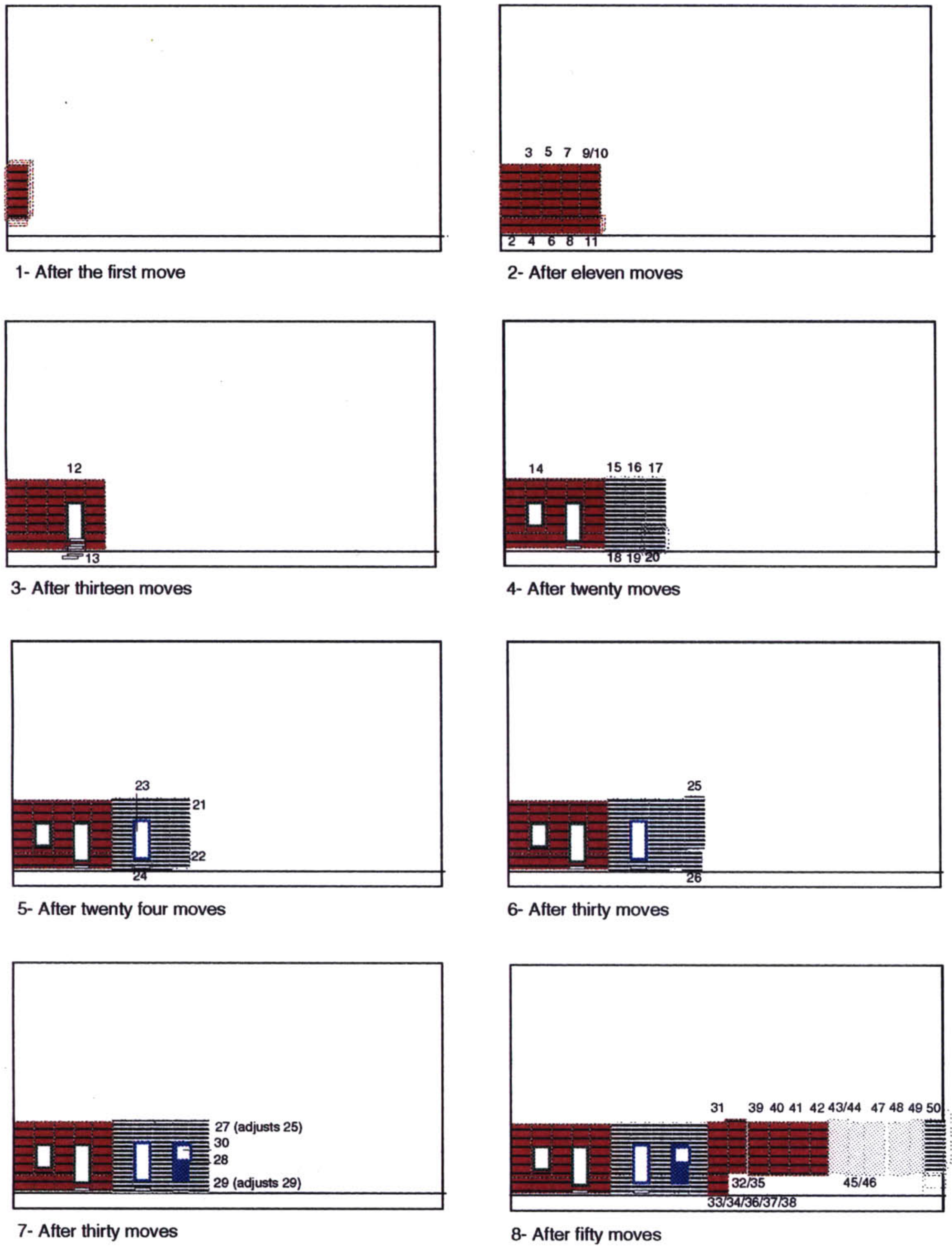
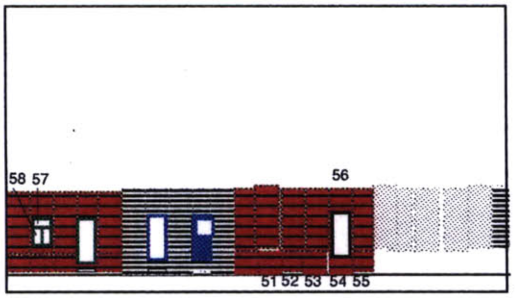
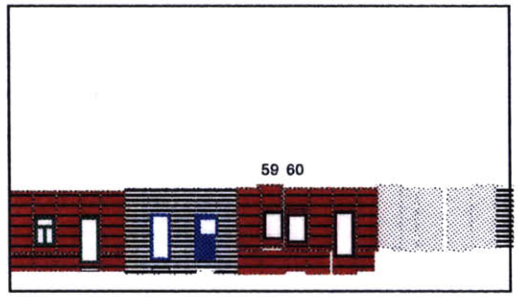


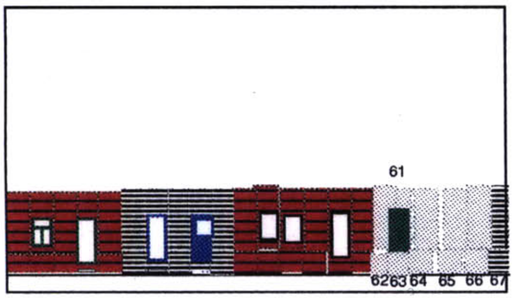
Fig. B.9
Ana's design process



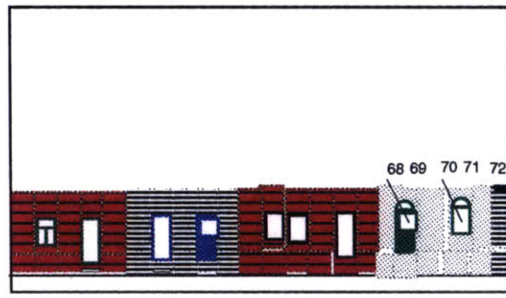
9- After fifty eightmoves



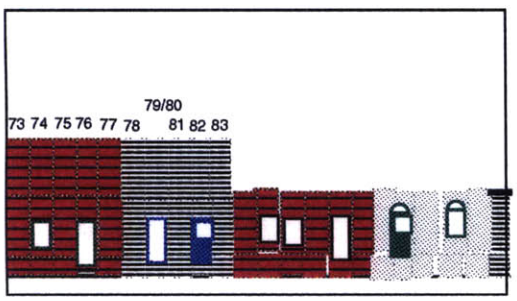
10- After sixty moves



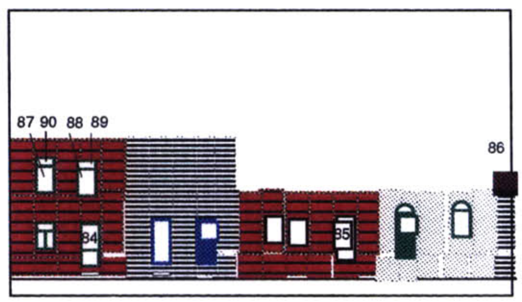
11- After sixty seven moves



12- After seventy two moves



13- After eighty three moves



14- After ninety moves

15- After ninety seven moves

16- After roof and correction

Fig. B.9
Ana's design process (continued)

Appendix B.2

Verbal Protocol

Appendix B.2

Verbal Protocol

Thomas' Verbal Protocol—1st attempt

The protocol was not transfered to text.

Thomas' Verbal Protocol—2nd attempt

Experiment

The protocol was not transfered to text.

Discussion

J: Do you consider it diverse?

T: I completely forgot about diversity. Well, it is repeating those things to a certain degree but (it) doesn't fill up the whole structure. And then there is two open () for the structure to be exposed once completed, and it's completely cladded, and the upper one is no completely cladded, and the windows are different, but the same color, the same repetition, so you can find some diversity.

Joan's Verbal Protocol

Experiment

The protocol was not transfered to text.

Discussion

Jo: Yes, compositionally.

J: Compositionally? why?

Jo: Like a... street facade, shops, you enter at the ground level, and then we have windows here, there. And may be we'll have street courses. So, I was thinking that way. I don't know. And I was worried about to put all these pieces... on the facade, and not worry about the structure. Except where titwould be exposed. (Joan)

Wade's Verbal Protocol (1h 55m)

Experiment

Note: Wade was one of the 'designers' involved in the attempt to make the Spoken Game with Architectural Shapes using Timbuktu to connect the two computers (see section 4). As explained in Section 5, the slowness of the computer prevent the use of such set up. In a first attempt to make the experiment with Wade without the Timbuktu the computer, for some reason, crashed after 13 moves, which obliged me to restart the experiment a second time, right after the first. I reproduce the verbal protocol of that first attempt below, since Wade refers to it one or twice.

1st attempt.

W: I'll start with a small beam. Just in case.

Let's see... I am going to change my mind.

Another small beam.

I don't know where the windows are to be in later.

Now, I'll put the connector.

I'll grab another connector.

I am trying to get some type of structure that will let me have some sectional differences between the space defined by this tall column and the extra long upper space, a sort of a clear story space.

2nd attempt (right after the first one)

J: Have you any idea of what you are going to do?

W: Well, I am trying to recreate what I did last time. a sort of to raise the volume of the (...) Because I can't use cantilevers, I am trying to make it more interesting.

So, this probably is going to be some type of porch area.

Grab a long beam. Okay.

So,... Well, I need to follow the rule. I am going to make a long porch entrance space. This is different from the other one, so...I think I am going to reject this one. This seems to be short. I think this one is the size of a window and the door. So I can left the window next to a door.

This is going to be a central entrance doorway between the two spaces. Which is different from what I had before. I had the two spaces connected and the entrance doorway at ().

I am trying to see... to count the height of the various columns to see if I have enough to... levels equal at above. Okay, now I need some connectors up there.

[silence]

I am just trying to get the structure for the interior space first, and then I will put the panels and the windows later.

So, get a beam to raise the floor level. Okay. So, now...

I am going to need another connector up there anyway.

There we go.

()Build it with shorter columns. There we go.

J: what are you doing?

W: Well, I am trying get another... a second space within the first one and a... I am trying to get a porch in one end with a roof in extension covering it.

Oh (), I have to get some columns in here to support... I am not using the columns to... I mean, the columns are going to be for interior walls but obviously but some of them are going to be in the wall, interior. This is an elevation. So, you won't be able to tell that.

somewhere is going to be in a door

A connector to support this thing underneath.

Oh, shuut! I have to get a... Okay, that will be the porch. I have to got a porch and not a small cantilever. A porch on this side. So, that will be exposed, eventually. But I have a roof up there, but the roof is going to need a connector on the corner. So, I have..

Now, we have to support this thing with a column.

I am going to try to repeat the thing from the other side. I am going to try to repeat the small little...clear story on the other side of this.

Oh! I know now what I can do. I can put an internal light shelf there. Consider external... Something on the other side a sort of... Again this is designing by the (city of New Kansas). Okay. Now let's start putting some panels there. The volume up there is... There is nothing there, so let's put something that looks substantial.

So, I just continue to (immerse?) this masonry foundation *per say.*

That's interesting. I have... I forgot about the diversity thing, but I certainly have diverse clear stories.

Okay, go back to what I was doing. Putting the foundation.

So, choose the white brick for the main level, and the whitewash for the clear-story levels. So, start with the white brick and filling everywhere now that needs brick panels.

Talking about this idea of having to go back and cutting the holes and windows. I think the way... What's her name?

J: Dorothy.

W: Dorothy? The way that Dorothy was doing before, stack the windows on the top of the panels below, is more keeping the way that modular systems work. Unless...

J: That's why I used a hole...

W: But, I think it would... I don't know... If it...If it is a rule you have or not... I think it would be good to be able to stack the windows as you do with a panel, and also to cut a hole into a panel and put the windows.. So hat the windows can works as this large modular panel. So that you have two different window conditions: you can cut into a panel, and also you can use the window as a panel. So, that the windows start to work into two different ways. That would give you another level of variety... and also of difficulty.

Interesting about the way dealing with(the brick is getting into?) two clear-stories.

...

Okay. So, we're performing the same operation on this first space, and then doing the second space with the same panels.

Okay, now we have to go... now, we have the walls down... need to get to this clear-story level, build on this little white panels. Oh, they don't quite fit, but..

So, what I am going to try to do is... I think I am going to use this short band of panels on the top... that sit on the top of the middle size panels and continue that on to the second space on the bottom. So, what I'll do is just... finish

....

W: this is not what I was thinking about originally, but...originally, I was thinking about keeping like two stories space. Oh, well, we will see were the panels fit. I don't think the panels allow two clear stories space to happen...this risen space that I have here. We shall see. Oh, no! It will! It will. Yes, because I have panels the size of this tall columns and I have the small size columns. So...

Perhaps I should be using the step columns. Well, it doesn't matter. So, anyway to follow the rules, I have to support this thing. So...hum...what shall we do? Well, I need the column to support that anyway.

Let's see. I'll put it up higher, because that will redo step down again...step in this spaces is higher...step in this space is lower. No, I can't do because...hum...shall I put it up here...

J: If you want to pick it up again later leave it there.

W: Oh, because it is recording...So, anyway I have to finish off this space under rear. Oh well, no problem, I'll just... so far the spaces I have I know the volume...one column or one beam so, this won't be a problem.

I am trying on the far right end side...context in this...into larger space. Am I trying completely a stepping down to a smaller space, or leave it with a raised porch. That column has to be shifted.

What the hell am I doing? Where do I want to put that...I'll put it up here. Well, I'll put it back down here.

Once again we have to support the end of these columns... beams. It is frustrating to tell a person who likes cantilevers that he cannot have cantilevers. Let's support the floor... step this space down, or steep this space up. Are this two connectors here plus these two columns here equal to the entire height of one of this columns. I guess one of the longest columns is equal to the height of a connector, plus two of the medium size...I don't know what I want. I am just trying to finish this...perhaps, instead of figuring out what to do, I'll just do something and see what then it makes me think of. When you are puzzled it is better to do something, and just stop thinking.

I don't know if that's a function of the grid or just me but it seems I am mispositioning the entire...

I guess the program of this thing could be anything but... it looks like... It's probably a house.

J: have you been thinking about that from the beginning?

W: It seems from the beginning that was what I was doing but then, just now, I thought I couldn't have done something besides a house. But, since it seems that I am doing a house... that's better.

Is this panel as high as this medium columns? So, anyway, I'll take this... something that I did before... take this masonry units for the called space foundation area. It seems to be difficult to take a piece that has already been placed in this screen.

...

I don't know whether the foundation of the porch should be the same or not. So, I am leaving that to later.

So, I am using these white panels now, to articulate the entrance. Yes, it looks right. Oh! No, I don't want to... I'll use the large panel to define the door.

J: But you haven't doors now.

W: Yes, right. But I will have to put the panel before the door. So, I'll use a large panel to define the door area. Now it falls... the part window area. Yes, use the large panel for both the window and the door just doesn't seem right. So, again, I am using this small white panels for the zones that can be particularly used to openings, windows.

The commonalties are not in the structure, but in the panels. There is three different , sort of conditions of the materials in terms of just massiveness, and white is probably one of the real common... The plain white panels could be made of stucco, and the white brick is masonry, so it has some tectonic reading, but it has this white color. Then you get to the red brick which is larger in the size of the unit, and because of the color, which is a darker color, it is an earth tone, so it reads as something to be read as a grounding. Where as the red, the blue, the green, the black windows are basically... unless somebody as some type of methodological approach to color...

So... let's put to the rest of the white panels. So as I was saying, how people choose the design elements they are given to choose from. Basically, structural elements are structural elements. It's just a matter of arranging. I am trying to think about that idea of, of how people relate to the several, elements, and, and try to design at the same time.

So now we are filling this clearly story zone. I have to put some steps. People need some steps to get to the front door. That is a step, isn't it?

...

I was looking at PA, a trashy little American magazine. It's basically a picture of all of the recent works, essentially American. My studio mate has a subscription and he brought in the new issue. It has a new house by Steven Hall that uses..., and two pillar structural system for this roof is very peculiar. It's quite a beautiful house in Texas. Very impressive... hall's designs.

...

Maybe I'll start from the door.

...

I'll stick one more. well, when you'll go back to it, eventually it will fit. Very compositional.

...

I really have no idea where this design is coming from. I mean in my head. I had some idea of two spaces with a verandah, porch, maybe two. It seems that I have two.

I am starting to think that this smaller sections should have gone below this square sections, so that the square sections could line up with the square sections that are above the door.

Continue to have some kind of a band run from above the door across the top of this other panels. Perhaps I should put a door in their wile... I'll take the filled door, since there are two different ones. Probably I'll end up putting glass around it.

Perhaps the step should be underneath.. that the step should go up to the window, and that you turn to the doorway, so that the steps don't go directly up to the door, but go up to the side of the door so you went up to a landing, then you move horizontally. Oh, we can always come back later and move the steps over. Perhaps not...

I am using this small white ones to fill up the space. I'll stop using them. We'll fix that later.

So, I'll take these white masonry panels and put them down in this smaller space. Well, I have just had an idea of making these small space area a glassed area. I'll take this short white masonry panel and place it there so you read the band moving across the top. The white band moving across the top, and then down to this other zone. However it may look, it is not mere composition. I tend to do a sort of a zonal... I don't know, maybe it is compositional, but the composition defines zones as opposed to purely graphic.

I don't know what proportions are going to fit there. It is a sort of... The white band is not going to have glaze in this facade, because I am thinking of as the clear story happening in this stepped zone to the left hand perpendicular facade and the right hand perpendicular facade. So, this wouldn't be glazed here but back this way, and back that way it would be glazed. But it is going to be glazed around the doorway back here. Which it will give a clear reading of the doorway as opposed to the spaces enclosed by the walls on either side of the doorway. Doorway slash hallway separating the two spaces.

I misplaced, I have too go back. So, anyway those two big panels on the left hand side () because the smaller ones sort of the connector for a reading. The ()don't clearly define occupiable spaces, where this tall panels are about the right size to define an occupiable space. This small space on the left is going to be a conservatory size. Oh, let's go back and move the stairs to where they belong. I want to put the stairs on the right side of the door. Going back to that idea. I don't know whether I will follow the rules in trying to define this, because it is a change in plan. This is the first time that the plan has really stepped out of a plane because until now it seem this entire facade is a sort of a single panel. And by moving this steps over and having to have a landing is also the only place where the facade steps out.

Now I am going back to the foundation over the porch on far right side. It would make sense to use the same vocabulary as the other foundation, the dark brick. I am not using the white brick because it is slightly different from the dark brick and then it is not. It doesn't have an enclose above it. The white brick was used to literally enclosed the space an occupiable space. So it wouldn't make any sense at all to close that space with a red brick. And a kind of makes it looking good because a kind of give it a balance underneath. And on the other hand on the other side you have this very light layer of white and the light of the white panels where the () is going to go. Above and enclosing the space, whereas on this side down below you have heavy look with this sort of stepping on one hand end it steps out and roof plain and the materials step sort of on the opposite direction. There is a sort of a diagonal progression across the facade.

I don't know if I will use that element. I know where it would go well.

Slight displacement. No, I want it here.

I want a solid band above the window. That would the registration of the floor height, of the head height for that space. Again that Schindler frame idea.

J: Where you thinking from the beginning about putting a glass area there?

W: Initially I thought about putting a verandah and a open space, but since I have one on the other side of the house, having one on this side doesn't make a lot of sense to me. The question is, do I continue the band or do I use this as a bridge. No, what I think I will do is to continue the band, so it is going to slide over the door.

J: Have you noticed that you are putting the windows on a beam?

W: They were not meant to be on the beam, but below the beam. But at this time I cannot see clearly where the beam is.

Now I need to put some windows around the door way. Let's see...let's go across the top of the door. This time I am not sure whether I want a band, a gray band above the door.

The more tired I get, the more I end up doing just some compositional things. If it turns up that gray band...that there is no room for that gray band there, those windows can certainly go directly above the door.

That was a little too big. I'll throw it away and I will grab the square one.

That looks about done.. Feels about right. Considering that I can't work with the other elevations. The other elevations might inform these but... It seems that I have, one, two, three, four, five spaces slash zones. the porch, three living spaces, just based on size or some type of living space, and an entrance, corridor, and then step down to another living space that has an extension to a glassed, glazed space that's tied to that living space.

Discussion

J: How do you judge it in terms of diversity?

W: In terms of diversity? Oh, god! I don't know. I mean, I certainly didn't try to make it uniform. I tried to keep some consistency in the application of objects and relationship to objects. So, I didn't try to use the objects... differently each time I used them. So, I didn't use diversity in that way. Probably a diversity more in... Oh! It's scary!

J: Do you consider it diverse?

W: Ahhh.... There is some diversity in level changes, in ceiling heights... I mean... there is variation. Diversity and variation are not exactly the same thing. I think it could be more diverse. I was thinking of it as being a little more ambiguous in the use of certain use of materials. But then, it might also be completely unreadable and ununderstandable. I think if you could form a experiment with a second person that had to analyze this and trying to use that understanding to generate another facade, based on those rules, then, it might be easier to do. It sounds perfectly reasonable. But of course I am no longer the one who made it, so... Of course I can read it. I don't know.

Taylor's Verbal Protocol (1h 25m)

Experiment

T: I am just collating these shapes. The machines permits me to put all the shapes over any other shapes all the time? It doesn't require to have some doing element, a beam next to ...?

J: It does require.

T: It does require.

J: those are the rules that I have been telling you.

So, that's really the only rule. So, I need to build up an all concrete frame first. And then hang my...

J: That is up to you. You just have to be aware that they have an architectural meaning. These are beams, those are windows...

J: this is something that someone else designed. What I am asking is to look at this design and analyze it and in your design you should follow the same rules. But, your design should be different.

T: I am not sure I understand what you mean by rules.

J: You have to look at this facade and try to infer what were the rules that ...

T: he or she used...

J: yes, and then you have to follow the same rules and design something different.

T: So, you don't want me to create my own, you want me to respond to that.

That measurement thing up there doesn't, does it?

J: No, it doesn't work. If you want to know the scale, a person is about that size.

T: I have to measure this.

J: Have you any idea about what you are going to do?

T: Me, right now? I am going to built a frame concrete building than I am going to hang these wall panels on it. Does all of these wall panels need to have a structure behind it to hold it up?

J: Yes.

T: What I am asking is that...

J: They don't have to be fixed on the bottom and the top. They can be fixed on the bottom or on the top.

T: Okay. How come that building look so much bigger than mine can possibly be?

T: It is difficult to place these things accurately.

You want diversity, right? That building isn't very diverse.

J: Why do you say that?

T: Because there's essentially...I guess he used different types of wall panels, but... I guess it is diverse considering the shapes that you have. It comes across as a building that uses primarily this material. I guess that diversity doesn't have to mean an equal amount of m(?) . Is that how you define diversity?

Diverse could be people, right? My first inclination is...to believe that a diverse building means that you have in it an equal amount of many different elements. And it doesn't come across to me as an initial amount of red, an initial amount of gray.

How long do you want this facade to be?

J: It's up to you.

T: What did you the scale of a person is?

J: About this size.

T: Oh I have just selected a shape I didn't mean to select.

J: Why did you select it?

T: I wasn't thinking, I just selected this one, but I meant to select that. I am not thinking very clearly.

.....

T: I think right now, it's just a matter of building this concrete frame. I created a much higher space up here than I had done here. I am trying to do myself a little bit of diversity in terms of distance. I have started a larger pattern over here. I think I have got to define a series of moves and then I go on to something else. Once you started setting up columns, you clearly have to continue to make it work.

J: Why were you hesitating?

T: I was just trying to... because this part on the left side of the screen I had...I knew pretty much what I was doing. Then I was trying to get an idea about what I was thinking. The connective elements? Why are they even there? I don't really find a need for them. It seems to me that the beam elements are enough.

J: Because they represent a building system that was designed in that way.

T: ... have cantilevers and things. Is that the idea? Not making each element with a connective element? I am just trying to explore possibilities.

J: You cannot have cantilevers.

T: Why not? Inventing new rules as we play? Just joking.

Can I put these connective elements at the mid beam?

J: No.

T: Just at the ends. There were things that I would change now, if I had the freedom, but I don't.

J: What would you change?

T: I would reverse these two. So that they could come and intersect this level up here. I like cantilevers.

J: why?

T: Because it is easier to create outdoor spaces.

J: Can you say something about what you are trying to do?

T: Yes. This is obviously a kind of a tower element. Then I am trying it to be a kind of cascade. This actually in response to this building, some kind of a reverse of that. A reverse composition. Is it possible for me to go outside this boundary?

J: No.

T: I'm help by the time be. This comes to help like this, or so, it has just occur to me that I can make this a higher element, which means that somehow I get some section here, where I can imagine a some light and visual contact between this way and this way. Yes?

J: Yes.

...

T: Did you see what I did? This was not be up there originally, but eventually something interesting. I feel. Okay, three of this in place, and then. Did you did this smaller because this took too long?

J: No, it just the size of the screen.

T: Let's just see how big that was. Yes, this the same size of screen. It was done right here. It just looks for some reason deceiving.

I have a question for you. A I am working on this, since I started to clad it... It's very easy for me to take a [...] approach doing that. Do you want me actually to thing about it as if I am cladding a plane surface of a concrete surface, or can I kind of use this different colors and different shapes to suggest relief?

J: That's a good question. As the shapes and colors stand for elements of a certain material, you should use them in that way if you think it would work well in reality.

T: Oh! Okay. But I can do it only if I see it happening in reality.

I though it was compositionally awkward and now there is some sort of continuation through the building. So compositionally, isn't quiet like the other on but, oh well...

I am just going to put one more column and then I will bee done with the structure, and I will go over styling!

Is the roof a pitch roof or what?

J: Yes. If you want a terrace, just don't put anything.

T: Oh, I see what you are saying. It's time for the cladding now.

What ever I will put on last, will overlap what is already in, right? I mean, if I want to put a window down here, I can't put before I will have the cladding on.

J: Why do you want to put the window now?

T: Because I have this theory that ...first you can do is to put down what you know and it helps to inform the rest of it. And the problem is I don't want the cladding to overlap it.

J: You can put the window again later.

T: I will try just to put the cladding on.

J: Why don't you just try to explain to me what your intentions were?

T: Okay. I will show what I mean. So, that's the way I work...

T: I like the blue. I really wish I could just draw a box where I want my window instead... I mean, I knew this all thing about elements that I am filling... I wish I could just bump a window here, bump, bump, two more windows, but then I can have what ever size that I want, and that's not the idea, so... It wouldn't be necessarily one of the shapes that you gave me.

You told me to follow, a kind of react to this, I am a sort of [...].behind that steel cladding, is it steel cladding?

J: No, it's white brick, remember?

T: Oh, that's right, white brick. This is red brick, that whitewash. How come this person didn't put a roof on?

J: He chose a terrace. Why did you select that size?

T: Because I know it fits in there and I want this to be a kind of consistently vertical feeling, element, this kind of tower. I know I was told to react to that picture. I feel a little bit bad about it know because I can't get excited about this, I just want to keep going...white brick, let's see.

....

I like this whitewashes.

....

I want to increase the band between here. This is going to be a series of panels, and this is going to be a series of windows. And this is going to be another material.

...

Because I misplaced those windows, this one is going to fall over a column. What this person did that I didn't do was these kind of random clusters of windows. I did not choose to do that. Almost directed grid that I have created. I am afraid I wasn't a very good follower in this case. You still have a cornice in a flat roof, correct? This person didn't even use a cornice. I kind of want a top light here. This is a danceteria.

J: When did you decide that?

T: I have just been thinking about the way things work. This is a southern facing facade, because I don't want a have many windows on it, so the space inside you can certainly believe, make this quite contained, my feeling is that is going to be some sort of art school, this is a street facade, the real light is going to come from the other side, which is from the north that gives a more diffuse light. What's really bizarre about me is that I should have decided this thing before. And I actually I have been thinking about this spaces, this large spaces, how do you get light into it, how do you designate an entrance. I think I have done that. Would you know where was the entrance of this building?

J: It is not finished yet. But, was it intentional?

T: Very much so.

....

T: Uau! It looks pretty good. And you should always have something...some cool, this was what I am going to do.

J: Are you going to put a window.

T: You always need something exciting (isolated window). I can pick any one I want. Oh, no red is too... Maybe green, maybe green will look better. Green is closer. My grandfather's favorite color was green.

Discussion

J: Do you consider that diverse?

T: It's no less diverse than that.

J: What do you mean by that?

T: I claimed that this wasn't diverse. I don't think it is particularly. I think, yes, he used all the different pieces, this is diverse in terms of, 1, 2,3,..., 14 different elements or something, it's not as diverse as it could be, but I think it falls in the category of basically diverse. This is as diverse as that. This guy used some chaotic window type to try to create diversity. I think it is a poor excuse for diversity. I have diversity here, in terms of, I am showing structure, I am showing glazing, I am showing panels, I am showing cornice, and I have different colors of windows, and different sizes of windows,...I have different sizes of panels, to some extent.... I understand, I take your criticism.

J: Well, I was just asking a question. Another question: why do you think it follows the same rule? What was the rule?

T: Well, there is a basic rule, it's basically orthogonal, box-like structure, series of boxes that mine follows as well, there is also having this kind of vertical glazed elements, and there is also this idea of having different fields of material, which mine as well does. I include this horizontal element, with this series of windows. I did that because I was trying to imagine how the space was inside, I couldn't imagine being here, unless was in a mall, or some very large discount store which don't have any windows. Which that says to me. It's about as good as the [...] club around here.

Salvatore's Verbal Protocol (55 m).

Experiment

S: How big it should be?

J: It's up to you, the facades are to be diverse.

S: That's the first!

I will design the facade of one house.

...

How much is the height of one column?

J: Three meters.

S: So, one story. Okay. And this... almost one room. Almost... Okay.

It will have two rooms in the front with an entrance in the middle.

Another room with three modules then I need two more to define the width of the... That's the last. I want one on the top floor... as having diversity... of the spaces. Now... How height is this?

J: One meter. Actually ninety centimeters.

S: Okay. Can I take all this piece together? No? So I have to put the column first. Now, the joint. Let's take one more of this. I only can have the roof in this way? One more of this and I will try the windows. Now, the windows are not the same module.

J: Because you are supposed to put them on the top of a panel.

S: But also... I don't get what I want... I want windows here, like this, and then... So, I can try windows like this...

A series of windows here, on a second floor. I should move this. What I won't do is... this window don't... Because of two reasons. First reason: the module doesn't correspond... What is the window's size?

J: Ninety centimeters. And the height is about one meter and thirty five centimeters.

S: So, from here to here is two thirty five. No, two twenty five. Okay. May be we should have half window like this. Here, the same size.

Here, I could re-select this and have this on the top of the... Now, I will select this. You don't have rails?

Now... I think... How could I Know the length? This is from... How much is this? Seven, ten meters? Seven, eight, nine... Here I have three, three and a half... so it's ten meters. Okay. How much is this? One, two, three...

J: It's four times one meter and twenty.

S: This is four, this is three, this is two, this one. So I don't have the module here. Let's try to put this and let's see what happen... Put a column here.

But now, I don't have the space. What could I do? Could, could use another of this. But is still too much space. And I need the joint. Otherwise... Could I use this, and go over like this? Erasing this, so the joint will be like this?

J: No.

S: I can't? And this is two, this is one. So, there is three in a... Otherwise... Okay. I know what I'll do. I'll do this. Starting from the other side... Let's... put this. I'll start from the beam, and then I will go down this way. So, we will have a kind of entrance and porch on this side, two-story high. Not two story. So I will have... No! I don't know. Anyway I have to think about. So, let's see. So, put apart this.

J: What are going to do?

I want to put this beam here. See, the point where this finish... and then go down. This... Whether put the beam in the space between, you know, this three windows. Up, what shall we put?

Ahh. Okay. Jump down... Okay, let me see. No, this space is almost... No, I want another space. Can I have another beam here?

J: Yes. But you need a pillar.

S: Ah, I need this? Also... So, do you know what I have decided to do? Just decided, I am going to have a column, here, and a beam here, and then, another column down this way. So, it will be, this kind of terrace, kind of freeing the structure from this. Because if I will go down this way I won't have enough space. Let's say like this.

...

The point of... where I move all these things. Let's say, the point of... where I keep the mouse is almost the center?

...

It doesn't matter (a misplacement). Let's say it's bad carpentry.

...

Now, I am going down like this.

J: So, did you choose your initial intentions?

S: Yes. Almost totally.

J: Why?

S: Because there are not enough elements for it, to do what I want to do. So, I just changed the composition of the elements.

And now to do something about robbery, I won't put the entrance on the floor, I will put the entrance here, they will enter, this double space, double height. I need to put another joint between this and this? So, let's put this joint here. Oh, I like this. Because you enter here and there will be flowers, you know... pergola.

Okay, now, we need the roof. This is a..

J: sloppy.

S: Like this? Yes, but what kind of material?

J: I did not think about it, so you can assign a material.

S: Ah, okay. So, they won't be tiles, but they will be... I would like to have a roof which is made of glass and another material, not transparent material. So, I could use this color to express that there is a non-transparent material. Then, I could use either the holes or the window frame but it will be not this way.

J: So, you don't have those elements. Those shapes stand for specific physical elements. The roof is in fact, the only one which is not very well defined.

S: Oh, okay. So, let's just use the roof like this. No, I changed my mind. I want an entrance with the roof here, then you'll have...

So, this is supposed to be restricted? Is this supposed to be repeated? You know, a series of buildings?

J: It's up to you.

Is not possible to enlarge the screen?

J: No.

This is the same size than this, right? Because I am assuming that the roof follows this string... even if it is not really allowed.

...

They are uncontrollable.

...

So, we have the roof which is sloped this way, right? So, I will have the roof this way on this facade. And what is this? Just a hole?

Okay, now it is almost finished, but when you go out here, you want this here. No? So, I think we'll do something... We'll put this here assuming that this string is supposed to be aligned with this, right? And this sides, because is where the column starts, in this part, even though there will be a kind of contour followed with the eye.

Okay, let's assume that's perfect. Now, shall we add... the entrance will get into here. We will enter this way. This side will be a kind of a closed street. Everything will be locked inside, except in the second floor where it's opened. This, this and people look down. Here it's very heavy, it's the light. Here are all these windows around the pergola here, so people can look down the entrance. And, what I want to have here, is just a... windows, so I will put a... Actually, I would like to have just a big window on one side.

I am trying to follow this, having this shape of the...

I am doing now this big window. So, the minimum room is supposed to be here. Look at the entrance, look at this 'patio', look at the street outside. And then I am going to put a small window like this.

So, I think I am finished. I am doing this big window, a small window here and I think it's done. I'll assume that there is a rail here, preventing people to fall down.

...

It's almost a temptation to reverse like this (the entire house).

...

What shall we do now?

J: Finish the design as you think and then We'll correct that.

S: The last thing I would like to do is to pull the roof until the column, so there will be more protection for this area, also more shadow.

J: Is it finished? Let's correct it together.

S: Yes. Let's correct it.

Discussion

J: Why aren't you happy about it?

S: Because there aren't really enough elements. A problem with size and everything.

J: I would like to ask you a question. I asked you to design facades that should be diverse, and you designed one facade, and I want to ask if you think whether it is diverse.

S: You didn't tell me that it should be diverse! You told me to design a facade with these elements. You told me that it should be diverse? I've just listened that I should design a facade. Anyway, I did so that... If I had to defend my project, it's diverse because I designed a facade which is not a facade. There is really everything: up here, there are whole this space, open spaces and () really have a door, windows, which are typical, but the entrance on this side, which is not very (), this huge window, with two meters by two meters, and then you have this portico, this pergola upstairs, and you only have this two-stories portico to get to the entrance. And we assume that the street is here. I designed a diverse facade because on the other side of the street we see the lack of other facade. Because we should go up the, this is the portico. The entrance from the street should be here... because everything happens inside. So, in this way is a diverse facade because it doesn't show the main entrance, it's a facade that shows the lack of an entrance, a kind of refusing, as saying 'what's the importance of this?' The inside, not the outside. In this case it would be diverse.

We are so much concentrated in the elements that we forget to think diverse, because, when you say you have to design a facade with these elements we just think the elements are not so many so we think: 'what can we do with these few elements?' My problem, and, psychologically we refuse the issue of diversity...

J: But you could have selected black windows, for instance, to put here. They didn't all have to be green. You have four colors for the windows.

S: Yes. This is a kind of... I like a kind of order, this doesn't mean symmetry. But I really dislike having all these windows with all different colors.

J: But what about if you had to design... go on.

S: Also... I think there is also a problem with the elements because there are a few elements. So, if you really want this facade be diverse you should say : 'Okay, let's just not just spend one hour but one day, let's try, let's just explore all the possibilities of these elements.' When you have this shortage of time available, especially because, I want to stress, we are in the week of the finals. You do more work with what you know and not with what you don't and you could explore. We could do something probably interesting, if you did this in January during IAP, let's say: 'Okay, this is the problem, can you spend one day, or can you spend one hour, then come back, and fix it and redo it?' But you are short of time to do this. But you should stress: 'explore the possibilities of the design with these elements' and probably we could get something interesting. But the elements are really very limited but at the same time, we are architects we should do better and we could do something.

Ming's Verbal protocol (1h 55m)

Experiment

M: I am looking at this design... the way it is heavy. It seems to be heavier at the bottom. And this level is divided into two sections with a roof on the top. And it seems like the windows, the light is always on the top. And there seems like a terrace of some sort because the beams and columns behave a sort of a frame that seems that it can be inhabited.

J: What are you doing?

M: Well, I am trying to figure out if there are any relationship, dimension wise that the roof as... whether the facade is divided into certain proportion. One, two, three, four. So, it seems like the roof is four to one, the roof, if I use the roof as the dimensional, the base, the reference, as a reference dimension, and there is four part to one. And it seems like three wall panels equals three and a half window space. I don't what that means, but... One and a half panels equals one square window. It seems that half of a panel, half of a wall panel in height equals the height of the square window. Can I draw another tracer so I can...

J: No, you can't.

M: I cannot.

(explanation of how the computer application works)

M: A beam is roughly the same dimension as four wall panels. One wall panel equals the height of the beam. Also one panel equals roughly four the width of the columns.

J: It is enough.

M: First, I'll take a beam, I mean a column. Okay, the column is on the ground. I will pick a wall panel to create a surface first... to match the height... No, maybe not. I'll create another surface.

J: Wall panel.

M: Wall panel. Oh, well (misplacement).

J: You can selected again.

M: If that is the case, I'll put a window and... it seems like... this can be a public area, so...

Public area is going to be at the street level, so I can have more windows. It seems I don't need the...

J: What public area?

M: Since this is a house, probably will be living-room area. So, I would think there should be more light in the public area.

I will enclosed the floor area, so the window is just... so there is certain diversity.

I am choosing a connector to be able to have a second floor. And there is a opening here, that can be some sort of a gateway. Taking a beam, picking a beam to create a gate.

The beam is covering the wall panels, which is not what I want. The panel will be attached on the top of the beam, so you should see the panel. I am creating a gateway now, and the I'll move the panel out. How big is the panel?

J: Three meters.

M: By...

J: One meter and twenty.

M: I am moving it to create a gateway, so you will walk underneath the beam between two panels. I'll move a window over.

I am trying to enclose the living area.

(restart because the program crashed)

I'll pick a column. The beam. Join the connector. I could hang the panel on the top. That might be a storage of some sort (left panel). Again a panel, creating a gateway. I'll pick another panel. I want to create the... There!

Okay. I put another panel, so I can put windows creating another panel. I will pick the window. Make it more public, by putting another window. Let's see, you enter... a foyer, one meter and three?

J: One meter and twenty centimeters.

S: Okay. One meter and twenty centimeters, two panels will be... two meters and forty centimeters. There will be satisfactory for a foyer. You enter the door, you have a view out. Let's see... These are the roof, or what are these?

J: These are brick. White brick and red brick panel.

M: I see. So, if that's the case I am going to put the red brick at the base. Bar when you walk. And then... another one. Let's see, our and a half. I am trying to create a texture. I picked a half height brick and I am putting the base course so... base to it. I would have to move the... I'll put a small window looking out at the foyer area. This center panel, so they can see out. I am going to create a wide wall panel to indicate that's an indoor space, a living area, rather than a foyer area. And I am going to move the window on panel over. There!

Now, I put a... What is this?

J: That's a glass door, a rectangle, and that's a small separated...

M: I see. And what is this?

J: It's an opaque door.

M: Opaque door? No, I don't want that. Even though is a public area, or somehow a public area, the living-room has still to provide some sort of privacy. I am going to try to enclose the house with some... picking up the white wall, the whitewash wall.

One, two, three, a bigger living-room. Picking another white wall. Another, give more light to the living-area, picking up another window. Putting it adjacent to previous one. I shall put a base to it. Put a ground level with a brick panel, a small one, put a base to protect against the moisture. The heaviest stuff on the base.

J: You are doing what?

M: I am creating a base course on the ground, so it's protected from the ground water... Oh, no...

J: if you don't want to use it put on the side.

M: Okay. And then, again, I'm trying to give a base definition. See, one more. Now, beyond that, I'm thinking that I will not put a bathroom in the front elevation but I'll enclose the whole building. You enter from outside, there is a foyer, and then into the living-room area, and so it is a front elevation. One more window there. There. I'm dirtying up... one, two three, four. So, the game is basically four panels long, spend four panels long. But, do I need to put a connector there? We will see it though.

J: If you don't see it don't put it.

M: A column... the stairs going up the second floor. So, by doing that I am trying to create a terrace, and another walk up from the foyer area, until the second floor. Pick another column to create a gateway. Put another connector.

My intention here is to create a gate and putting a beam over that and then I can see where the beam, how far the beam cantilever out. And no I will create an indoor space, and the outdoor space will be terrace area.

J: You can't put the beam there. The beam has to be between two connectors.

M: Can I take, can I put a beam here?

J: There's a small beam here.

M: So, then I can't cantilever out.

J: Cantilevers are not allowed.

M: Not allowed?! Oh, okay. If that's the case, then I'll move this. I'll put a small beam there.

Moving the connector to the side.

I'm picking a shorter beam. So...

I am putting the column back there... this... at the end of the beam. So, there will be the terrace area. And then, after that, I will span a longer beam to become an interior. Put the connector back.

I am going to start a panel to. And this might be, I guess, a rented (), for the renter, so the base would be different... The first floor would rented out, or the owner would live there. Now, I want to see the...

...

J: What are you thinking?

M: I am trying to enclose this area, the second floor area, so I can put cornices at the base line to separate the first floor and the second floor, and hopefully...

Another panel. I am going to put the cornices on. To differentiate the first level and the second level. Because, at this point the whitewash panel looks continuous area, so I m trying to define the differences in level. I'll move the... the window is to close to the cornices, so I have to move the window back.

So, I have a terrace in the front, and I see...

J: Where's the front side?

M: The front side will be here, where you enter there's the foyer and then you go up. So, it's separate entrance and... So, now, I am going to put another panel on the second floor.

Now, we choose one cornice to...

Since the lower level doesn't have any outdoor space, except the entrance I am going to create a backyard or something. So, there's a column here. Putting the beam. There. Put a column to a... a joint... I am expanding the upper level, creating a shape, some sort of a lower terrace. The foyer.

I am not sure whether I want to put a cornice there because this beam already implicate the floor level. I'll put another, a bigger one, on the second floor. I've decided I want a cornice to create that continuous line.

J: Do you want the cornice on the beam or over the beam?

M: Hum! That might be too heavy. Still I need to create this continuous cornice to indicate the floor level. I am not sure... I am going to put it there and maybe I'll change it later. To a composition wise?

J: What do you mean by composition?

M: The... composition in the sense that... the proportion of the lines, for instance the cornice and the beam together might be too heavy at that point, maybe too thick, so I might remove... At this point I am not sure, let me keep going... Let me put a... let's see, probably some sort of a more open area because it's higher, so there is more... there is less privacy problem. So, I am going to take a three, a third panel to give a little privacy. It jumped up!

(change macro)

I think the cornice is okay. I think at the base I need to finish the base course.

Let me finish the third floor. Window above the short panel. And I'm assuming this, to the third level will be an interior stairs rather than exterior stairs like the first floor to second floor. So, the third and the second floor will be probably the same unit.

I'm assuming that there is a nice view back there, so I am putting a big window there. And, well... at the front elevation... No, I won't do that... because this will be a street facade, therefore I will put to enclose the room... Now, cornices. Now, I don't like that cornice, is too dark.

Okay, . Now, I want to put something there to differentiate.

J: What are you looking for some sort of to indicate break this and, this floor line, and I am not sure that... let's see this a wall panel, white brick, just for a, just has a end, I'll put a brick on the top.

And, let's see, put a window here, should put a window here to indicate the stairs the circular stairs, this is going to be an expensive project, high income. I select the window.

I just put this window to indicate the stairs going up the third floor, and I think what I will try to do now is to put the roof on. What is that?

J: Holes.

M: No, I want to have another window here because privacy is not an issue anymore, because the elevation changed, because it's a third floor, so whatever you see is the... is at the street level, you'll only see people, because of perspective.

...

I want to show... put another one here.

...

This stairs... What do I want to put? I want... No, I think I would try to finish it like this.

...

So, I am going put another back here. So, I'm putting a column here, so I can have a roof here.

Can I put a connector?

J: No.

M: If that is the case... I need a beam to carry the roof. So it has to come here and then I will cover this one... which is matched, however. Put here... and then here... which is fine. Okay, so what I'll do is I'll put a shorter column there.

I am going to put a small column there, I'll put a joint on the top and connect the beam over... If I put the column here then I have a space which, put the... I am going to put a beam across. Now... no step... Now... put here

Two meter forty. How big is this guy?

J: Three sixty.

M: I am going to put beam here, so I'll need a column down here, but I don't see it, so I'll just...

There will be a connector here.

...

If this comes up here, then I need to cover the beams. So...
So, this should be higher, this should be like that, isn't it? So, where is this guy set now?

So that means I'll put one of these. So this roof... Oh, okay, I'll put a roof over this stuff.

...

This I will put on here.

...

So, that provides a shade for this guy here, in the Summer, but in the Winter...
...
So, this roof is to shallow so it needs higher.

...

I'll put a panel over there.

...

Should I put a panel in there?

J: It's up to you.

M: See, I don't know graphically, how big this is.

...

This is more for a tropical climate, so this should be a higher roof.

...

This is a luxury house

Discussion

J: I have a few questions to ask you. Do you consider it diverse.

M: Diverse in, in, not necessary in elevation, but in level are changes that always express, for instance, I have very... very consistent open space, for instance, you enter into the house, so, there is always a space. It's the same language, but I think there is the diversity of the use. Of entrance, for instance, this becomes a balcony, this is the entrance, this is the terrace.

J: Do you consider the facade diverse?

M: The facade is not diverse.

J: But I asked you to design facades diverse, a diverse facade.

M: I remember.

J: Did you remember that during the all design?

M: To me, I guess, diverse in spatial, in sequence, is more important than just the diversity in elevation. To me that, even though the elevation itself looks, ordinary, the diversity of the outdoor area, the open area, since I would think you spend more time outdoor, there is a tropical climate, in use is diverse, appearance is not diverse.

J: I asked to reply to that design with the same rule. What is the rule? The rule I see as to me, it seems that this indicates some sort of terrace, so that is repeated, also what is happening... is that the upper level is much more opened. Apparently, it seems it won't have a problem with the privacy as much as... that's why I interpreted. So, the upper level is much more opened. It seems... this also tries to create some sort of gateway that... indication of entrance, and what I did is that I opened the... This small window, seems to indicate that might be a bathroom of some sort. I decided that the bathroom... you would not see it from the elevation. He also... this seems a living area, since it seems a living-area, I opened up.

J: Do you think that he follows your rule?

S: I should have followed the process because I don't know how he build that and this is important, because I first did the wall and then I did the openings and... It seems true for this part but it seems that for this part there has been more an additive process and not a process of doing the general, and then doing the holes. If you are talking about the rules in the process, I don't know, because I didn't follow it, but if you ask me if in some ways, you are talking about they have the same language I would say that very likely they do, because the point was having an unified form which was open. And also the other point was having everything happening in the back. Here it seems that is doing that, because the entrance is not... this seems to be the enclosure of a courtyard, which you get and then you get to the entrance, there is a terrace in the upper floor, this other terrace, but enclosed by this screen. The only thing that, the only formal differences are between these two parts which are a kind of conflictual.

J: Yes, but in general, did he seem to have followed your rule?

S: That depends on what you mean for rule. About language yes, about the process, I don't know because I didn't know.

J: What was the rule of the process?

S: First, I put this. Then I thought, let's open, let's move the opening. On the other side, I thought, let's move from the heaviness of the ground floor, to the lightness of the first floor, and I did this part, which is completely opened, which is completely like a pergola. And then there was the problem that the pergola couldn't fit the space, and I came up with the idea to move everything out, and to put the entrance in the back. So, to transform this facade in something, not in the main facade, main elevation on the street, but a kind of a lateral elevation, switching the meaning of the relation between, the elevation, the main elevation with the building and the street and saying in some ways that what's important is not the elevation on the street, but what's important is this part with this inside the house, the open space inside the house, the entrance the entrance inside the house, the courtyard, the terraces, and this is just a kind of a screen, something which says everything is inside and outside is just this thing. This last aspect I think we did very much the same.

M: In responding to Salvatore, I think that his process, my way of designing is more an additive process, rather than this more as subtractive, and that's a major difference.

J: But because of the small shapes, he also had to use an additive process.

M: Additive in the sense that, see, the way he did it was, he built up a whole frame, and then he put holes into it, whereas is additive of small things that building up to something. I think that's the big differences between each other.

Pedro's Verbal protocol (1h 35m)

Experiment

P: What are the dimensions?

J: A person is about this size.

P: That is not enough. I need to know more.

J: A person is about six feet tall.

P: Okay. Can I do this of any size?

J: Yes.

P: I am going to draw a big house.

J: It doesn't have to be a house. You decide that.

P: A facade. It can be a from palace... And what about the number of stories?

J: It's up to you.

P: I have no limit? Can I do is a hundred meters tall?

J: It has to fit in the drawing.

P: Should I draw a classic house, a..

J: It's up to you.

P: Even if it would collapse? I should start with the beams.

The design will be constrained by the things that you have here. If I was drawing freehand I wouldn't follow the same sequence.

Can I start with the non-structural elements and put them later?

J: You decide that.

P: So, I can place a wall and place the window on the wall? But, how am I going to place beam, for instance? Can I place it on the wall, even if in reality it would stay behind?

Let me start with the door. This is the ground? Can I put some steps? That's it. This is not a glass door, is it? So I have to put two things. Let's put another door. Let's put that thing that like too. The step is for last. Is it common to start with the door? Let me put the wall panel.

If I want more than a floor, can I put a stairs? If want two separate houses, for instance. No, it is going just to be a house.

This doesn't give you the idea that it is a white brick panel. It's to black for that. Let's put another brick panel and then we will put a window. Let's put the window. Are these two components of the window?

J: No. That is just a hole.

P: A hole? Why do I want a hole without a window? Do I have to place the hole and then the window?

J: No. You don't have to.

P: But that way I can't have a round window. Oh, so these two are separated elements? Is there any white window? No? So, I will put a blue window.

If I wan to put a wall over the window it will overlap the round element.

J: You can select it again.

P: This is not enough for a living-room. Let's alternate again and put another white brick panel. I like the white brick alternating with the red brick. I like the houses with brick on the outside facade. You will be able to see the brick, right?

Pedro's wife: You will built the house just for the right side?

P: No. Later I will draw the left side. Can you see what the idea is? I am alternating the red and the white panels. And the last will be a white on the corner. The house is getting big.

I am going to put a column. The column is shorter. Now, I need a beam. I have to place the connector.

J: What's the idea about what you have just done?

P: I've just build the right side of the ground floor. Now, I am placing the beam to start the second floor. I haven't decided yet, what I am going to do; if the second floor, if the left side of the house. How am I going to place the beam. I don want the beam to be seen. Can I put a panel on the beam later? Now, I have to put a column but... the column is going to be placed on the panel. So I will have to put another panel later to hide the beam. Oh, I see, I should have started with the beams. The architects start with the beams. You could have told me to start with the beams. Yes, that's true that in the building works they start with the columns and the beams. But drawing, it doesn't have to be necessarily like that. We are freer. I could let the beam to be seen, but it is a little bit ugly.

This time I will start with the beams and the walls later. I am starting with beams to avoid overlapping. Then, I am going to the upper floor. Two beams on this side too, and the door will be in the middle. One more column, and this side will be finished.

Now, I want to hide the columns on the right side. Do you have any narrow vertical brick blocks? Can't I cover it with brick?

The windows will be the last thing. Because I want to see other things. I am learning the essential about architecture. To put first the columns and the beams. But I think that the architects worry about aesthetics first and don't worry about the beams and the columns. Only at the end they try to find a way to place the columns. Now, I am going to place a window at the corner. It looks good.

I like things with many windows. I will place lots of windows. In terms of walls... here they will all be white. It is a little bit too high.

J: You can select it again.

P: You should have told me that before. I wouldn't have selected two new ones to hide the columns on the other side.

J: I did but you didn't understand.

P: I am misplacing everything. It should have some rules to make it easier. Do you want more diversity than this? Red and white brick on one side, white Wall on the other, blue windows. It looks horrible but...

And this completes the first floor of my house. Except the windows. Don't you have longer windows? I have to put several. Blue windows.

And now let's put one of this. This is where I will spend the biggest part of my time. The kitchen will in the back. The kitchen will be turned to north. This house is located on the north hemisphere. Now two more of the biggest windows. Let me explain to you that this is not to be like this. The windows are to be aligned. The small ones are to be in the middle, but the big ones are to be all aligned.

Let's finished the upper floor. Where is the roof? Oh, the roof is like this. How am I going to do this? Oh, I know, now I am going to make a symmetrical house. I am going to put something like this in that side. I am going to put the beams and columns first.

It should be possible to copy things because now that is what I would use. I would group and copy them.

I would like to make an upper floor with two levels. But that would mean to spend the entire night here. I would like to draw a sloppy wall. If I were drawing, that is what I would do. Anyway, I like this like it is. Can I put a verandah. A cantilevered verandah. That is what I would like to have: a verandah, and a sloppy wall.

I am happy with this idea. The upper floor being the symmetric of the first one.

...
You can't explain this. You, architects like to explain things. This is not explicable. It is just inspiration.

...

I don't understand this idea of the holes. A hole? For what? For a monument?

...

Probably in this floor the window game will be different.

...

It is almost. A few more windows and the roof.

...

Now let's put the windows here. Here the composition will be different than on the right side.

(move 79)

Can you see? This window in the middle. In Alentejo, all the houses have blue on white.

This side will be different. To disrupt a little bit the symmetry.
This is going to be asymmetrically symmetric.

...

This house is too be located in the outskirts of a city, but in the country. Near pine-trees, surrounded by a glass field. It has a basement, which I did nit drew, because I it was not possible. I just have to put a step under the door... and the roof. It has four rooms in this side.

...

Let's put the roof. A dark rectangle about this side and a chimney on the right. I also would like to put a chimney in the middle.

Discussion

J: Do you consider this diverse?

P: Diverse? Yes. Let's say that it is classic but non-orthodox. It is a combination between the traditional, the lines that are rectangular, and the composition of colors and windows, where there is a great diversity. And it is uncommon.

Ana's Verbal Protocol (1h)

Experiment

J: Speak! What are you doing?

A: I am going to try to draw facades, attached, not very tall, to be faster, and attached, because as there are no trees it would look a little bit desolated, if left empty spaces.

I didn't want the doors at the ground level, and as I thought that we could distinguished the big modules from the small modules, I decided to put the bigger on at the same level of the door. Do I have to put the doors after the panels? I am going to put the windows after the doors because I don't know how... It is boring to build the walls. We should be able to put only the windows, because the windows point out the painted area. One more... because the window cannot be attached to the door. There should be bigger walls... There should be higher walls...

The brown should be closer to red, because this way it looks like wood. Can I ask you something? Should I put a panel behind the door? The door is smaller... I am influenced by the building where I live. A door and a window.

I am going to put a door. The black? The green?, the green is to light. Let's put a different color. I am just going to put just one step.

And now a window. I am going to make it fancy. No...In this I am going to put some decoration, but later... I think that my Beacon St. is going to change to a fishermen's neighborhood. But a fisherman's neighborhood in Portugal doesn't have... Let's pretend that the brick will stand for tiles. I am undecided. On one hand, I have to create diversity, one the other... maybe this house will be a house with two doors, because a door is always obligatory.

Let me see, how many houses will fit on the screen. Four facades. It won't be possible to put much more than one window in each house. There aren't much freedom. I know that there will be an element that I will put at the end, just to compose. I am not going to put beams, anyway we wouldn't see them. I don't like... it is picturesque, but I prefer monumental. I would like that in this house the door... as in this house I am going to put two doors, I would like to... I have to left always a wall between to doors, I think that the doors shouldn't be attached. I cannot put the door onto the first panel of a house. I think that doesn't work. It has to be at least a piece of wall.

The houses... I think that five seems to be the minimal number of panels that they use. Unless they have a facade with one door. The door doesn't need to be in the middle of the panel, does it? What the opening holes?

J: Holes without window.

A: I see. I don't think I will use them. Now I m going to put some doors to decorate it, if not I spend to much on this. But this house... wait... diversity... anyhow, I cannot forget that I am drawing houses, therefore, diversity cannot be so, so big. There must be a minimum. I mean, I think that in a facade I shouldn't mix doors of different colors. Even in the same street, I think that there should be some codes, imposed. Let's suppose that I am designing houses for small families in a not too dense zone. These are all glasses doors, it's not very appropriate. Now, I am going to...no, let's suppose that I am in a good climate. Even here they use glass doors, two doors, a wooden and a glass door.

These walls frame the doors. Why do we start to draw the house from the bottom... I feel like fill the picture. These houses don't have to be so decorated. Can I put a glass on the door? Otherwise there will be too much contrast. Can I try to put a window there?

This street makes me think about a fisherman's village, near the beach, with a good climate, the doors are above the ground level to prevent the floods, the windows and the doors are painted with happy colors, and the facades are made of wood, the houses are not very tall, only two will have a first floor. They small, are modest houses.

For a matter of diversity, both second floors will be on the left. The doors are made of glass, the people like light... I've used all the window types. Except red windows, because I don't like them. I think they are too... Well, diversity, it has to be a certain coherence, glass doors, well the environment requires light and so the people prefer glass doors, unless they are very private. Diversity has limits. In the same house I am not going to paint the windows with different colors. I know I am very conservative, but...

All the doors have steps. The doors are climbing.. well the street can be sloppy.

Let's put the cornice. I will put only one, but in fact I want them in all the buildings. I will do the same with the roofs, you will know. Well, there are three panels and five windows missing. The windows shouldn't have an unique big glass. I think it should be divided. I have to divide the doors. They can't have such a big glass. A children could break it.

For a matter of perspective, the windows on the upper floors cannot be higher than the windows on the lower floors. Can they? Yes, I am going to put higher windows there, just to try. The left house will have... no, I will simplify,... the windows are smaller than the panels you said? So, there always be a space in between. Well, I will put the roof while I think.

I will put two windows. A simple and complicated one. Above the window. I will put some more glasses on both sides, it will be the living-room window. I don't know why, I want narrow glasses on the sides.

These houses will also have a cornice and a roof on the top.

I just have to put the window here.

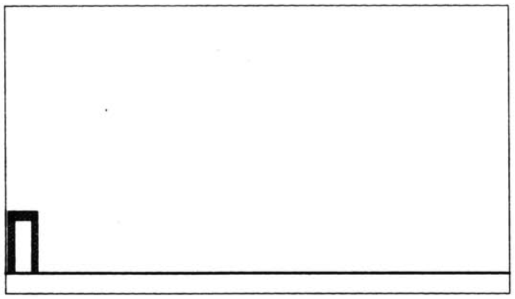
Discussion

J: A few questions. Do you think this is diversity? Why?

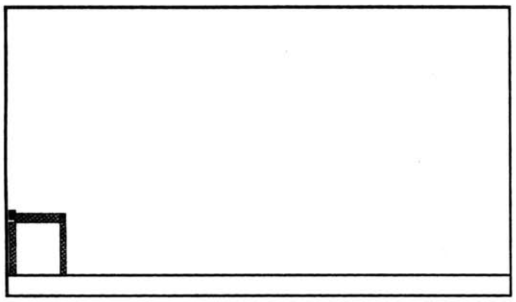
A: I think it is enough diverse: the color of the facades, the color of the doors, the number of doors, the height, the type of windows... If it were rigid, or if it obeyed to a common structure, they would all be brick facades, all with a door to the street, with the same height... For me, this is diverse. Of course that inside each house, everything is ....

Appendix B.3

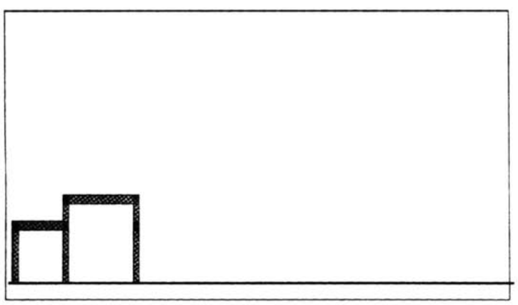
Graphic and Verbal Protocol Analyses—Graphics



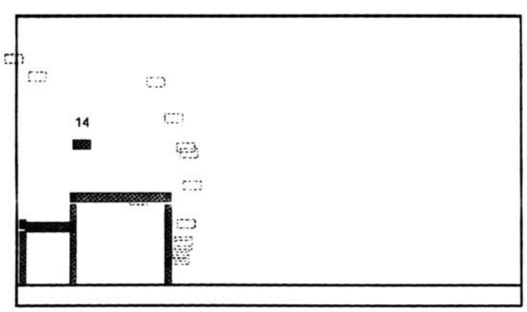
0 - Possibility not selected



1- After six moves



3 - Possibilty rejected



4- After fourteen moves (move fourteen)

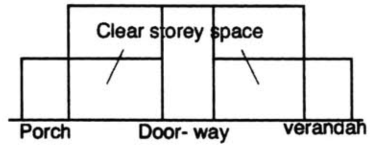
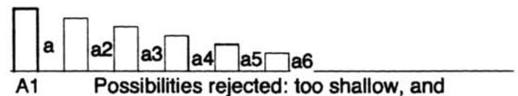
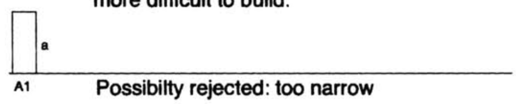


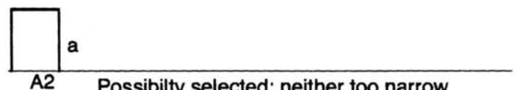
Diagram of Wade's initial idea for his design



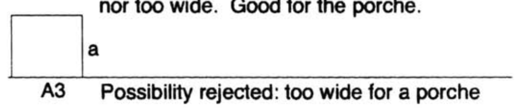
Possibilities rejected: too shallow, and more difficult to build.



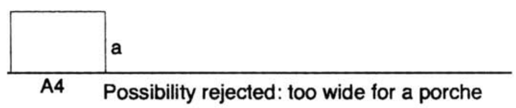
Possibilty rejected: too narrow



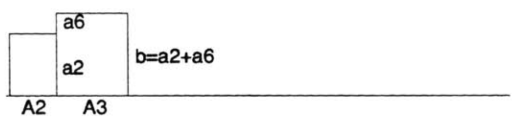
Possibilty selected: neither too narrow, nor too wide. Good for the porche.



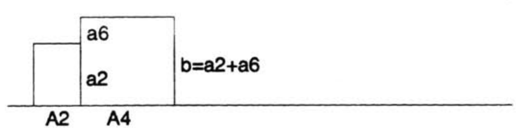
Possibility rejected: too wide for a porche



Possibility rejected: too wide for a porche



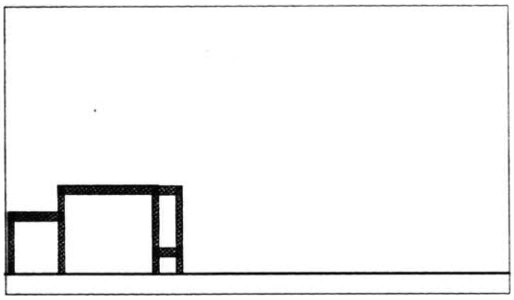
Too narrow. Too ambiguous; there is not a clear distinction between porche and 'clear strorey.'



Clear distinction between 'porche and clear storey.'

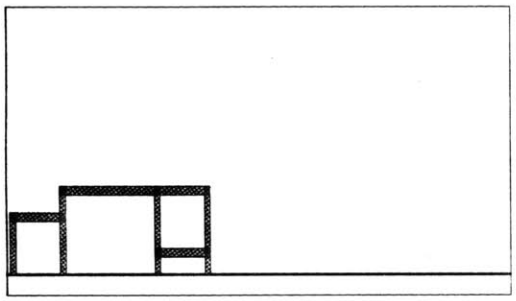
Fig. B.10

Analysis and interpretation of Wade's design

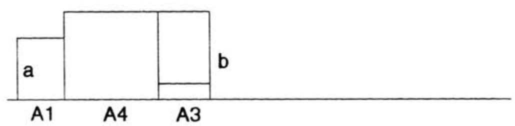


5 - Possibility attempted but rejected.

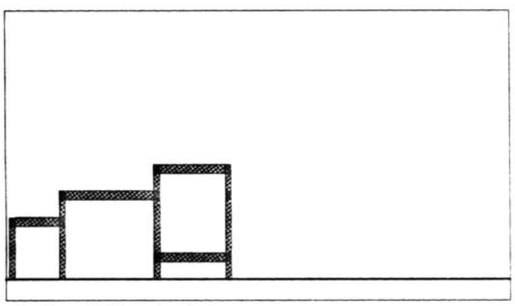
Diversity: span; good. height; bad.
Too narrow for the doorway.



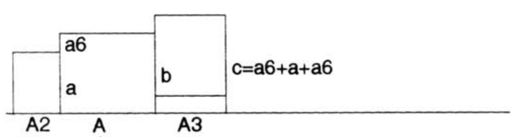
6 - Possibility rejected.



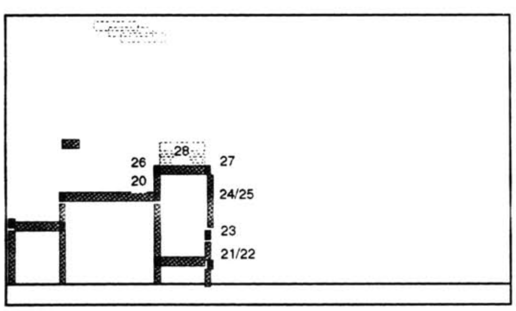
Diversity: span; bad. height; bad
Balance: good.
Good width for the doorway.



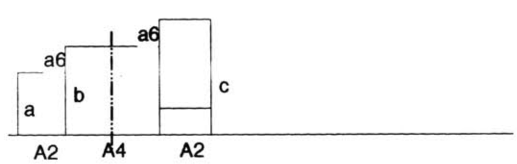
7 - Possibility rejected.



Diversity: span; good. height; good.
Balance: worse than above.
Too wide for the doorway.



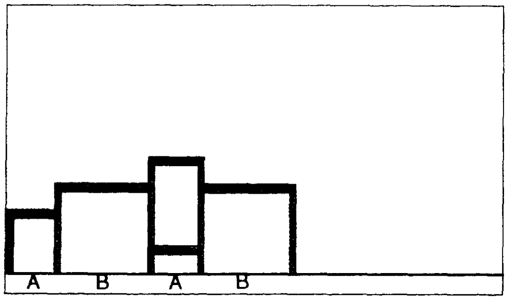
6- After twenty eight moves



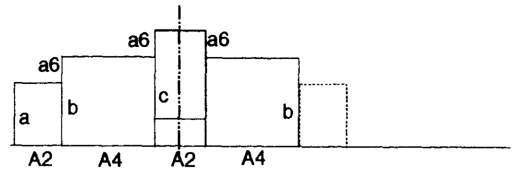
Diversity: : span; bad. height; good.
Balance: good.
Good width for the doorway.

Fig. B.10

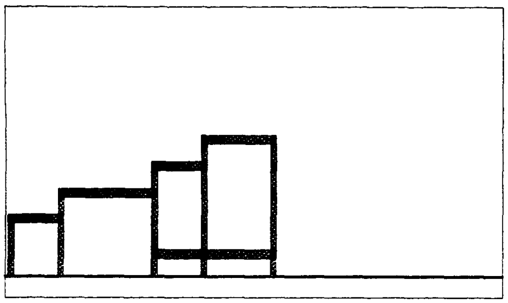
Analysis and interpretation of Wade's design (continued)



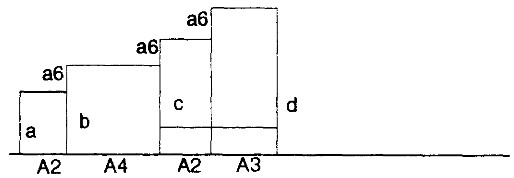
9 - Possibility rejected.



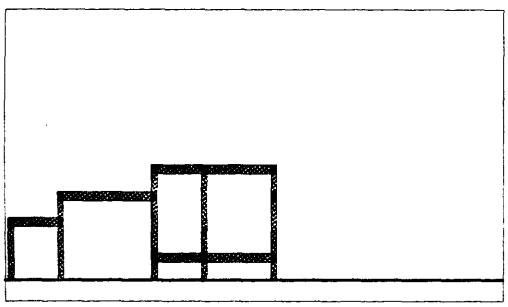
Diversity: bad
Balance: good
The drawing would become clearly symmetrical.



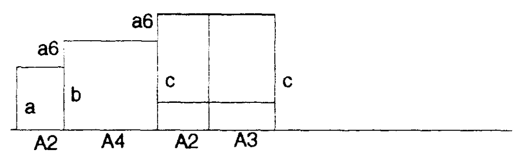
10 - Possibility rejected.



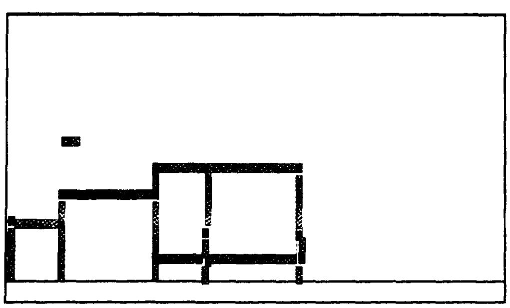
Diversity: span; good. height; obvious repetition of stepping.
Balance: bad.



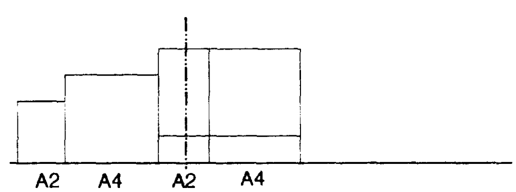
11 - Possibility rejected.



Diversity: span; good. height; better.
Balance: better but bad.



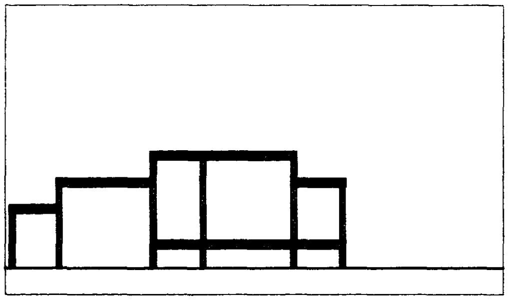
12 - After forty moves.



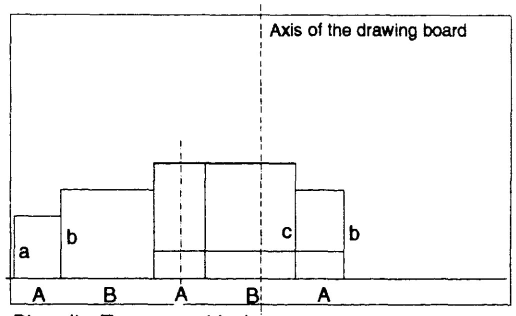
Diversity: span; worse. height; identical.
Balance: good.

Fig. B.10

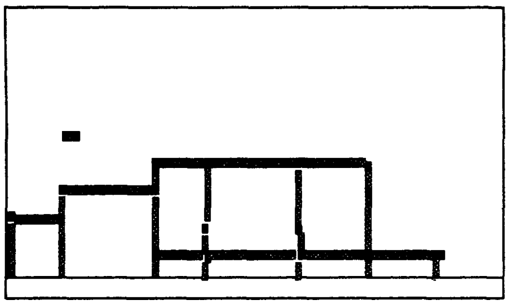
Analysis and interpretation of Wade's design (continued)



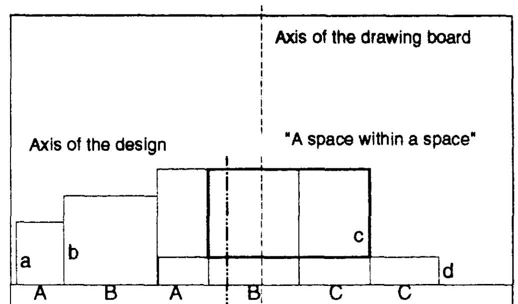
13 - Possibility rejected



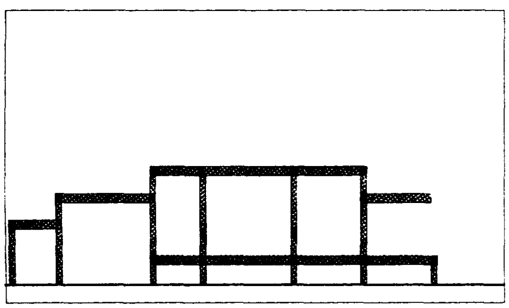
Diversity: Too symmetrical.
Balance: Expand the drawing to move its center towards the center of the composition.



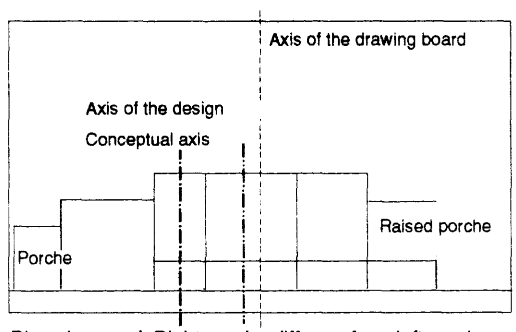
14 - After fifty five moves



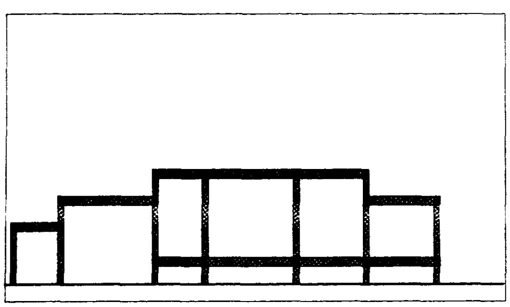
Diversity: better. Balance: better than above; center of the drawing closer to the center of the drawing board. 'Bad'; porches too different.



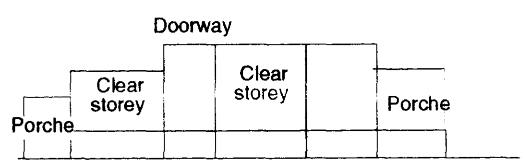
15 - Desired but impossible: cantilivers not allowed



Diversity: good. Right porche different from left porche.
Balance: better. Center of the drawing closer to the center of drawing board. Right porche similar to left porche (ambiguous reading).



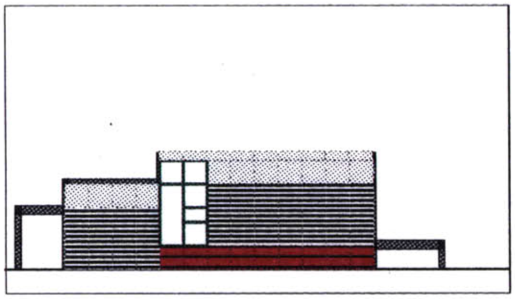
16 - Possibility rejected. Avoid obvious symmetry.



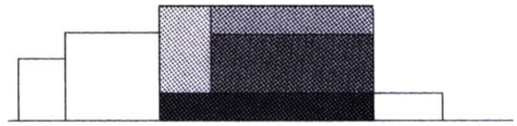
Diversity: worse. Right porche type equal to the left porche type.
Balance: better

Fig. B.10

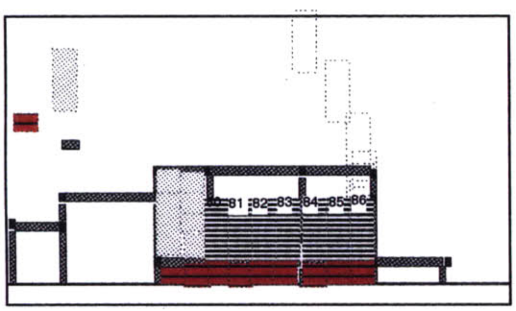
Analysis and interpretation of Wade's design (continued)



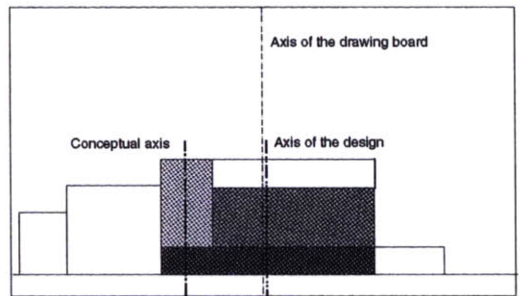
17 - The design according to the 'cladding rule' stated by Wade.



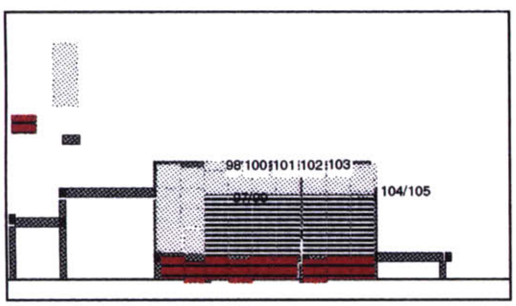
17a - The structural diversity would be hidden.



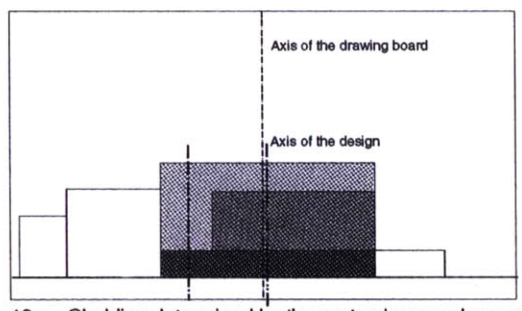
18 - After eighty six moves



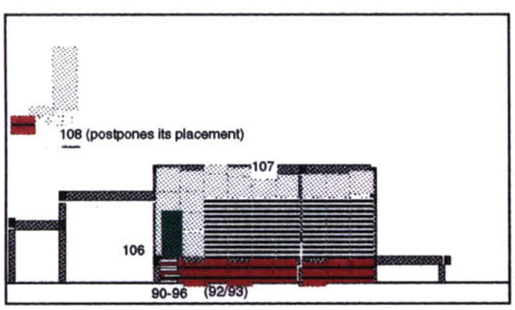
18a - Cladding required by the system's procedure that required that the windows should be placed on the top of panels.



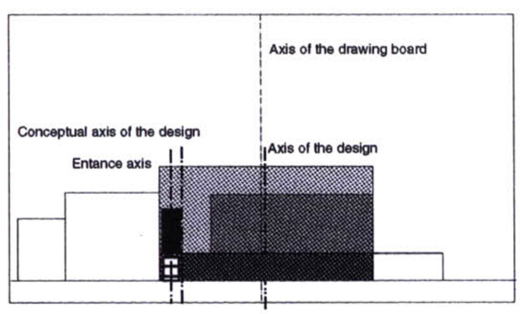
19 - After a hundred and five moves



19a - Cladding determined by the system's procedure and by Wade's rule. Emergence of the 'L' shape.



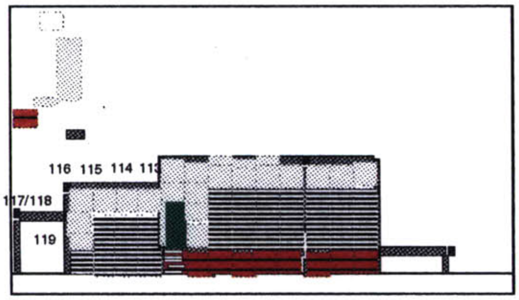
20 - After a hundred and eight moves



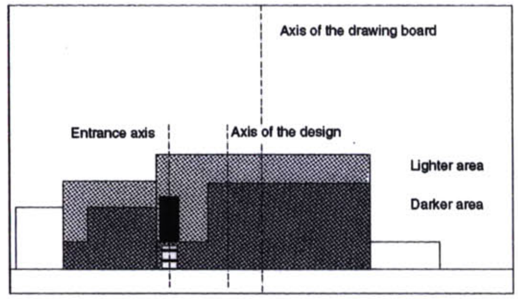
20a - Door and stairs placed. Entrance axis non-coincident with conceptual axis.

Fig. B.10

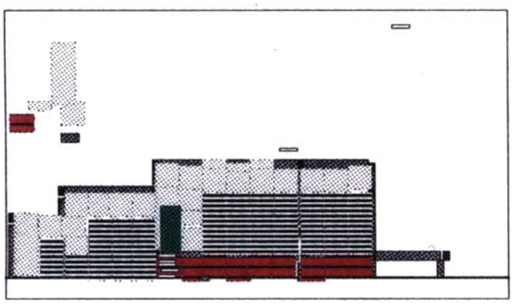
Analysis and interpretation of Wade's design (continued)



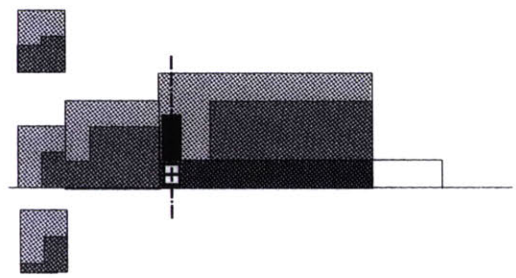
21 - After one hundred and nineteen moves



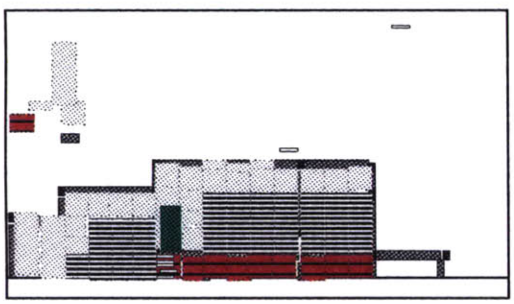
21a - Wade's interest for the 'L' shape caused him to disrespect the cladding rule he had established before. The axis of the design moved to the left, moving away from the axis of the drawing board.



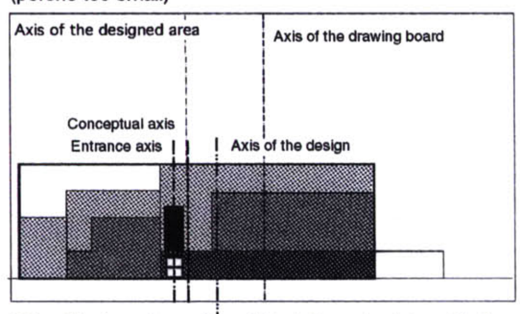
22 - Possibilty rejected



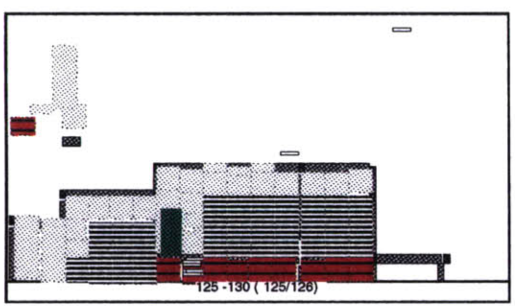
22a - Wade did not continue the "L" shape motif on the left porche since that would not generate an interesting design (porche too small)



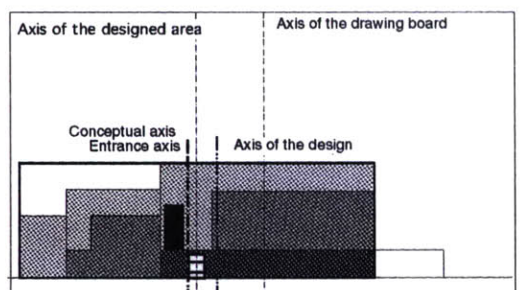
23 - After one hundred and twenty three moves



23a - The transformation of the left porche into a third area made the conceptual axis coincident with axis of the main body of the house.



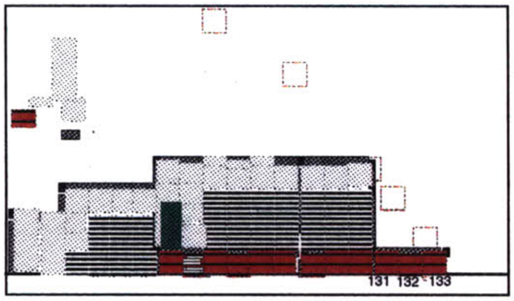
24 - After one hundred and thirty moves



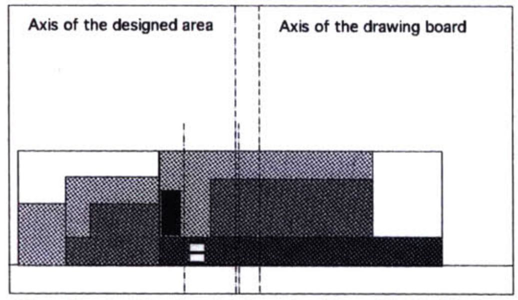
24a - The design with the stairs on the right side of the door. The entrance axis moved back to the right, closer to the conceptual axis, closer to the axis of the main body of the house, and closer to the axis of the design.

Fig. B.10

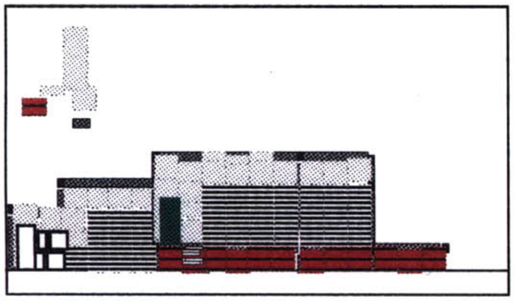
Analysis and interpretation of Wade's design (continued)



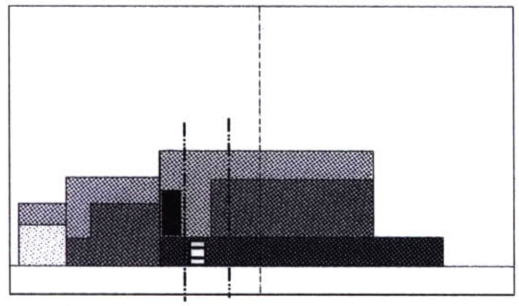
25 - After one hundred and thirty three moves



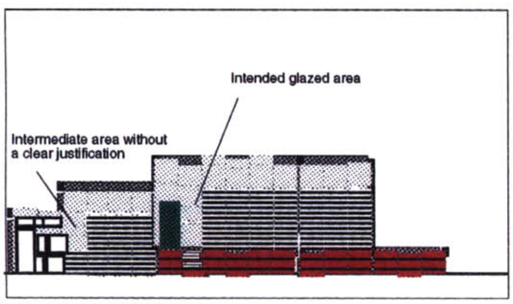
25a - By cladding the right porch with red-brick, Wade balanced the composition in the drawing, moving the design's axis closer to the drawing board's axis.



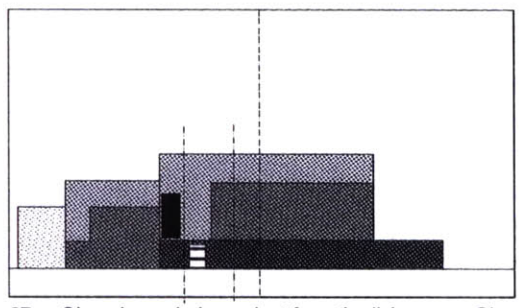
26 - After one hundred and thirty eight moves



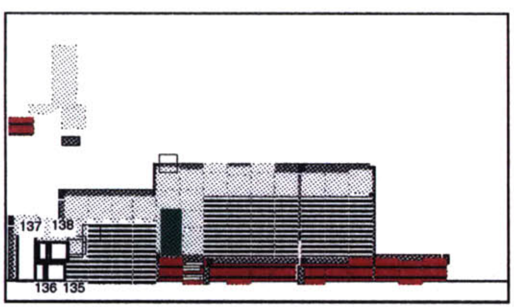
26a - By glazing the left porch, Wade replaced the conceptual symmetry of the design.



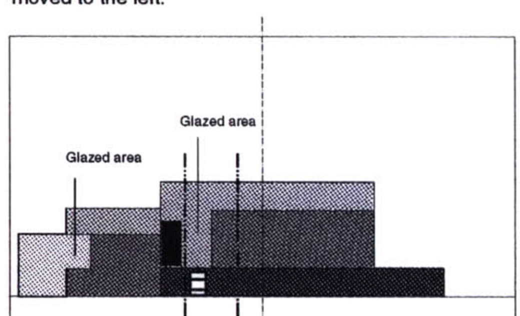
27 - Possibility rejected



27a - Glazed area independent from the living area. Clear reading of the different volumes. The axis of the design moved to the left.



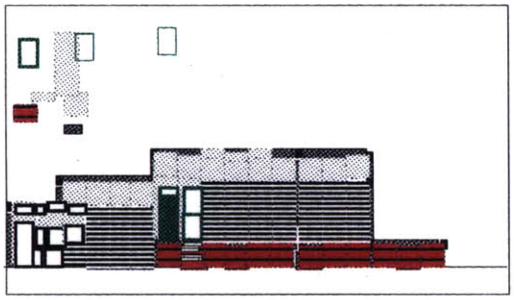
28 - After one hundred and thirty eight moves



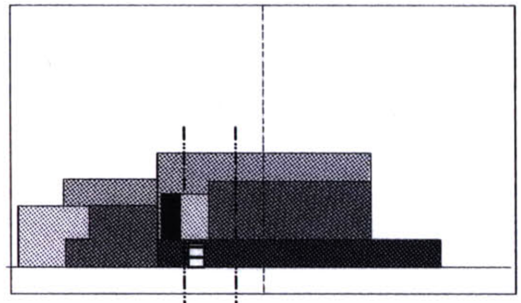
28a - Connect the porche and the left 'clear storey' space.

Fig. B.10

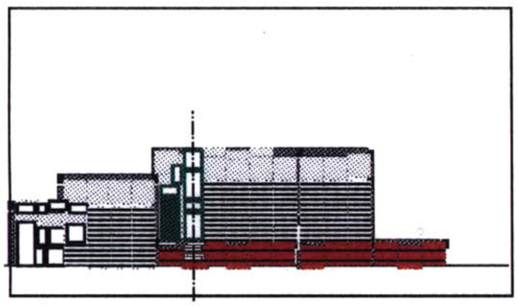
Analysis and interpretation of Wade's design (continued)



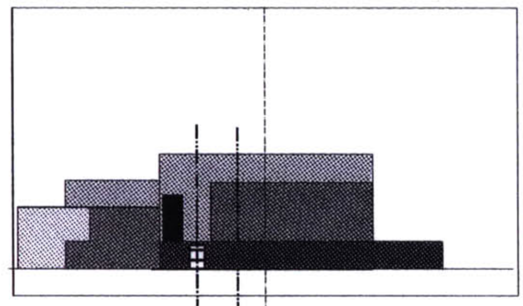
29 - Possibility attempted but rejected. Move 150



29a - The alignment of the top of the window with the top of the door reinforced the reading of an axis on between the door and the windows more distant from the center of the composition.



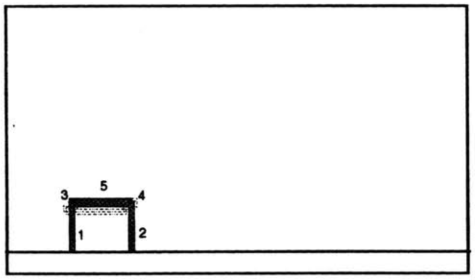
30 - Final design: : a compromise between contradictory rules.



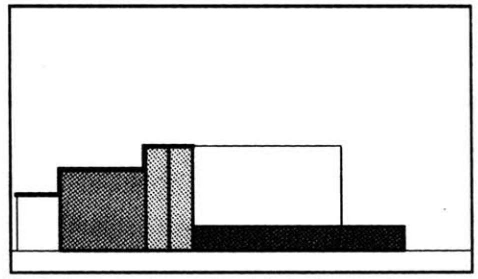
30a - The selection of a a small window reflects a compromise between the need to reinforce the reading of an independent vertical band of glass in order to move the axis to the right, and the need to keep that area as a glazed area, as initially intended.

Fig. B.10

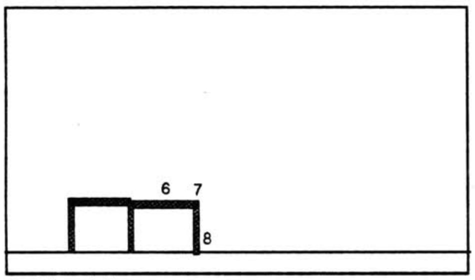
Analysis and interpretation of Wade's design (continued)



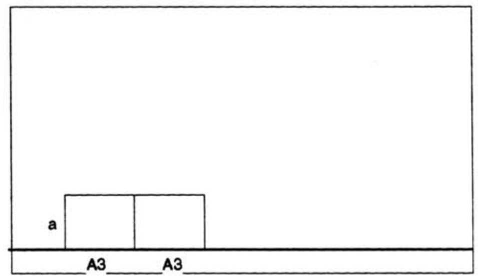
2- After five moves



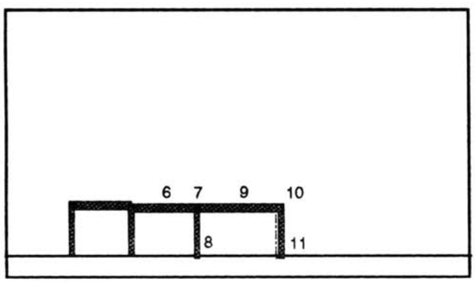
Taylor's abstraction of Wade's design; synthesis: a square, a vertical glazed element, a horizontal band, and a kind of cascade.



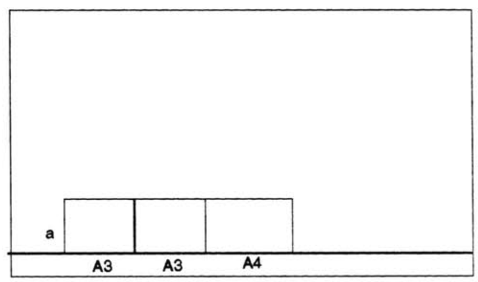
3 - After eight moves



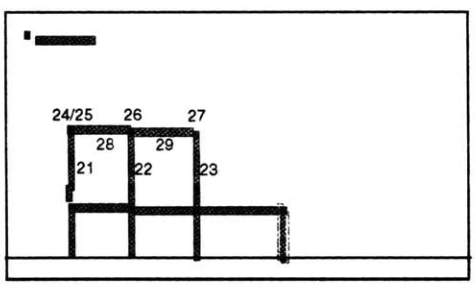
'How come that building look so much closer then mine can possibly be?



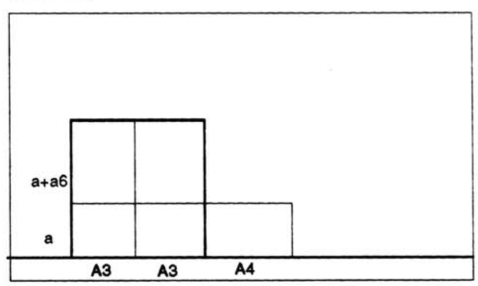
3- After ten moves



'How long do you want this facade to be? What did you say the scale of a person his? (Taylor's verbal protocol).

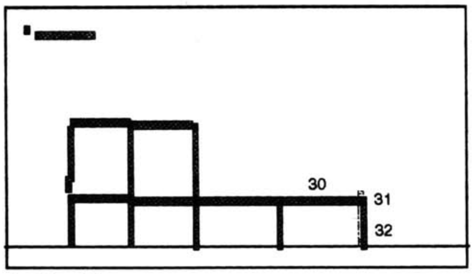


5- After twenty nine moves

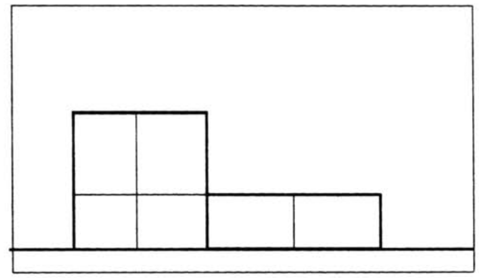


'I am trying to do myself a little bit of diversity in terms of distance. I have started a larger pattern over here' (Taylor's verbal protocol).

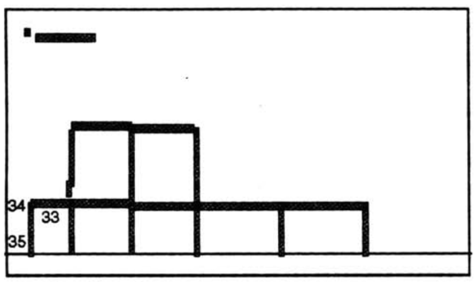
Fig. B.11
Taylor's design process analysis



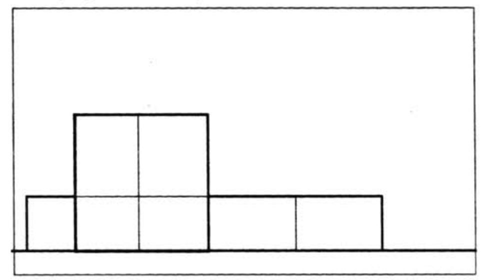
6- After thirty two moves

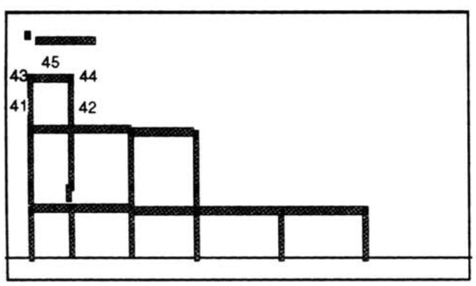


I am trying to do myself a little bit of diversity in terms of distance. I have started alarger pattern over here' (Taylor's verbal protocol).

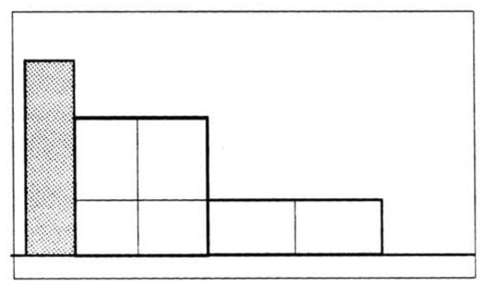


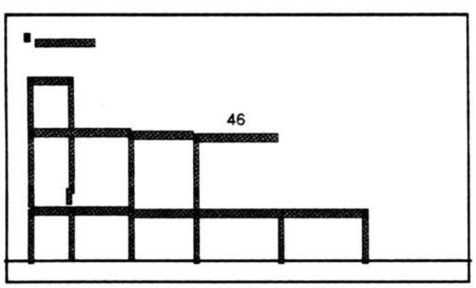
7- After thirty five moves





9 - After forty five moves





10 - After forty six moves

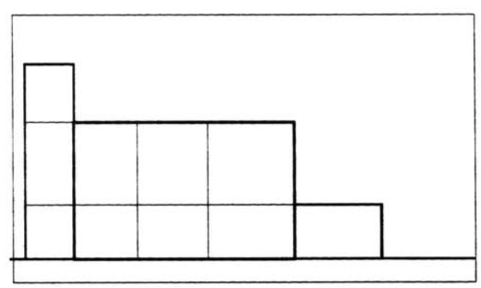
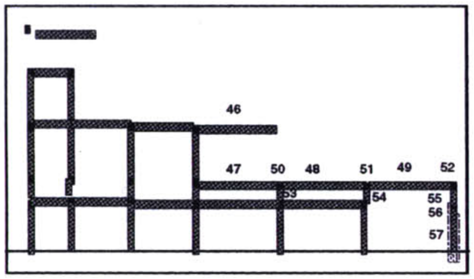
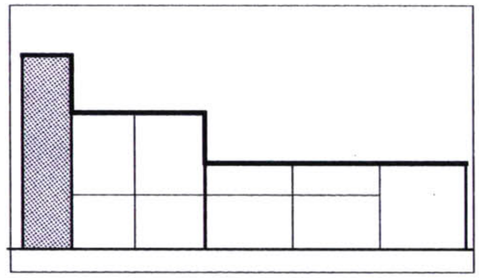


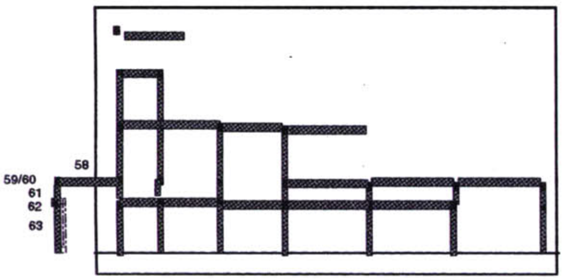
Fig. B.11
Taylor's design process analysis



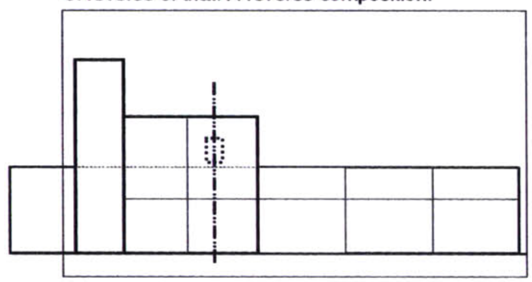
10 - After fifty seven moves



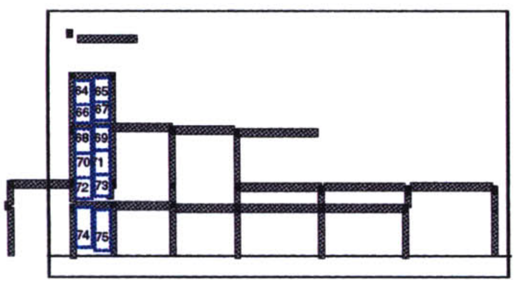
'This is obviously a kind of a tower element. Then I am trying it to be a kind of cascade. This is actually in response to this building, some kind of reverse of that. A reverse composition.



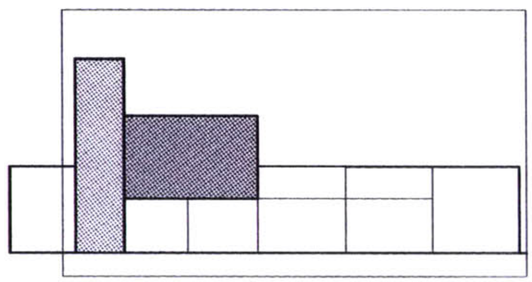
11 - After sixty three moves

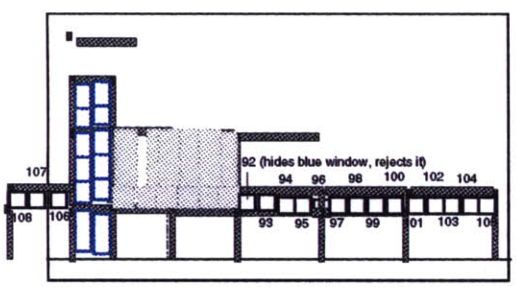


If I want to put a window down here, I can't put it before I will have the cladding on



12 - After seventy five moves





14 - After one hundred and seven moves

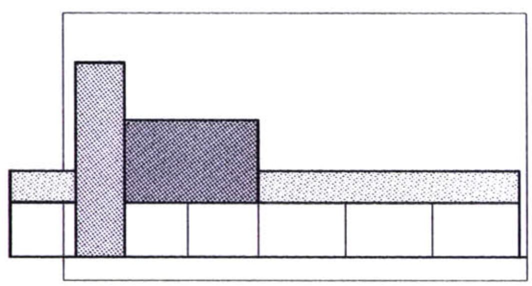
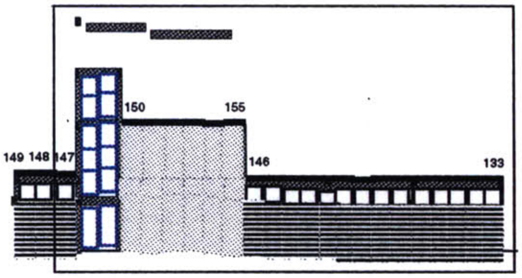
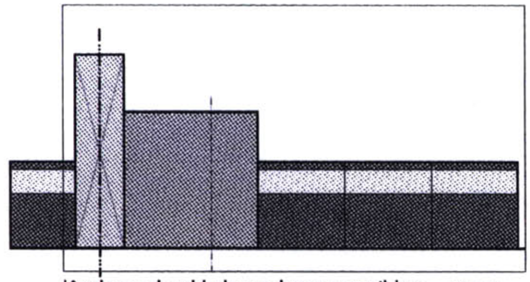


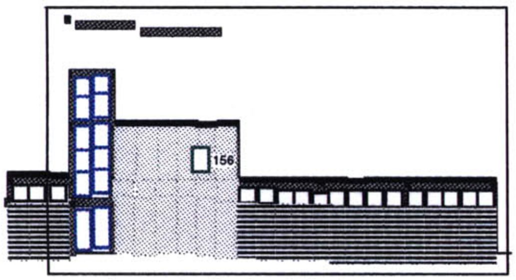
Fig. B.11
Taylor's design process analysis



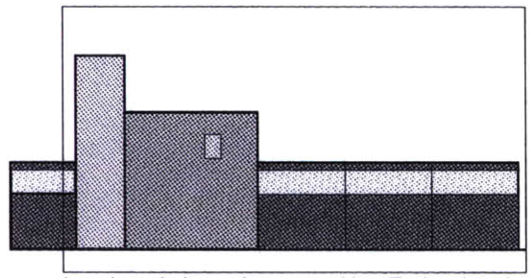
17 - After one hundred and fifty five moves



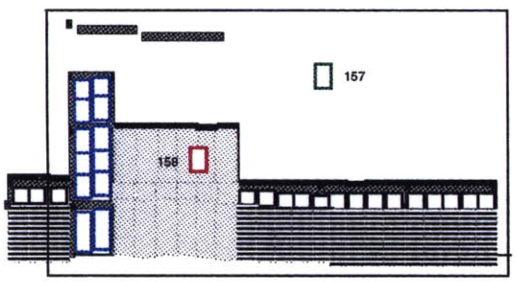
'And you should always have something... some cool... This is what I am doing to do...' Due to the stronger effect of the glazed tower, the design looked unbalanced.Unconsciously, Taylor felt that and decided to place a window.



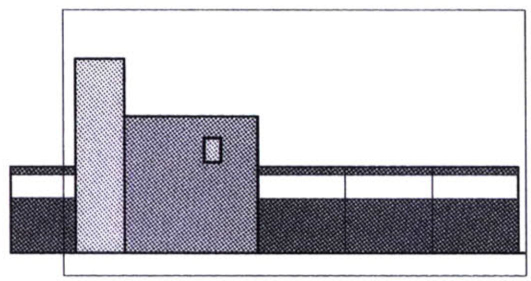
18 - After one hundred and fifty six moves



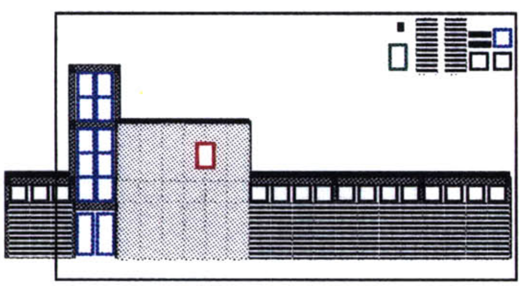
In order to balance the composition, Taylor placed a green window on the axis of the composition.



19 - After one hundred and fifty eight moves



Nevertheless, because the green window blended too much with the rest of the composition, it was no strong enough to balance the composition. Therefore, Taylor substituted the green window for a red one. With that move the composition became finally balanced.



20 After correction

Fig. B.11
Taylor's design process analysis

Appendix B.4

Graphic and Verbal Protocol Analyses—Tables

Table B.I
'Spoken Game with Architectural Elements'
Experiments and Designers

Exp.	Designer A	Exp.	Designer B
1	Thomas (designer)		
2	Thomas (designer)		
3	June (designer)		
4	Wade (designer)	5	Taylor (designer)
6	Salvatore (designer)	7	Ming (designer)
8	Pedro (non-designer		
9	Ana (non-designer)		

Table B.II
Verbal Protocol Duration

Designer	Designing Time	Correction Time	Discussion Time	Experimental Time (total)
Wade	113m	---*	2m	115m
Taylor	80m	---*	5m	85m
Salvatore	42m	8m	5m	55m
Ming	90m	10m	15m***	115m
Pedro	80m	12m	3m	95m
Ana	75m**	3m	2m	80m

* Correction done later
**Includes an estimation of the protocol lost
*** Includes discussion with Salvatore

Table B.III
Speed of the Design Process

Designer	Tot Number of moves w/ DT	Designing Time w/DT	Moves/Time
Wade	154	113m	1.4
Taylor	114	80m	1.4
Salvatore	56	42m	1,3
Ming	87	90m	1
Pedro	88	80m	1.1
Ana	97	75m**	1.3

Table B.V
Number of 'Effective'* Moves with the 'Design Tracer'over the total number of 'Effective' moves

	Th.1	Th.2	June	Wade	Tayl.	Salv.	Ming	Pedr.	Ana
N w/ DT %	29 ***100***	40 ***89***	59 ***82***	128 ***91***	109 ***72***	47 ***100***	80 ***92***	86 ***71***	86 ***67***
N After DT %	0 ***0***	5 ***9***	11 ***18***	13 ***9***	42 ***28***	0 ***0***	14 ***15***	36 ***29***	42 ***33***
Total	29	45	70	141	151	47	94	122	128

* Does not include correction of misplacements

Table B.VI
Number of moves to Correct Misplacements over the Total Number of Moves with the 'Design Tracer'

	Th.1	Th.2	Joan	Wade	Tayl.	Salv.	Ming	Pedr.	Ana
N correct	7 ***19***	10 ***20***	11 ***16***	26 ***17***	5 ***4***	9 ***16***	7 ***8***	2 ***2***	11 ***11***
N effective	29 ***81***	40 ***80***	59 ***84***	128 ***83***	109 ***96***	47 ***84***	80 ***92***	86 ***98***	86 ***89***
Total DT	36	50	70	154	114	56	87	88	97

Table B.VII
Types of Moves over the Total Number of Moves* without the Design Tracer

	Th. 1	Th.2	Joan	Wad.	Tayl.	Salv.	Ming	Ped.	Ana
Change position due to misplacements			2 ***15***				2 ***14***		
Reject a placed due to misplacements					6 ***12***			1 ***3***	
Put aside an element rejected before			1 ***8***	1 ***8***	1 ***2***		2 ***14***	1 ***3***	
Reject a placed			4 ***31***		1 ***2***				
Select and Reject									
Re-select a rejected			1 ***15***		2 ***4***		1 ***7***		
Select and place		5 ***100***	5 ***39***	12 ***92***	38 ***80***		9 ***70***	34 ***94***	42 ***100***
Total	**0**	**5**	**13**	**13**	**48**	**0**	**14**	**36**	**42**

* Does not include simple correction of misplacements

Table B.VIII
Types of Moves over the Total Number of 'Effective'* Moves

	Th.1	Th.2	June	Wade	Tayl.	Salv.	Ming	Pedr.	Ana
Change position	2 *7*			5 *4*	0	2 *4*			
Reject a placed			5 *7*	2 *1*	2 *1*	4 *8*	6 *7*	1 *1*	
Select and eject		1 *2*		7 *5*	2 *1*	2 *4*	2 *2*		
Re-select a rejected			1 *1*	1 *1*	2 *1*		5 *5*		
Total Number of moves reflecting change	2 *7*	1 *2*	6 *8*	15 *11*	6 *3*	8 *16*	13 *14*	1 *1*	0 *0*
Select and place	27 *93*	44 *98*	64 *91*	120 *89*	145 *92*	39 *84*	79 *86*	121 *99*	128 *100*
Total	29	45	70	141	151	47	92	122	128

* Does not include any correction of misplacements

TABLE B.IX
Graphic Protocol Analysis
Number of Elements, Kinds of Elements, and Colors/Textures

	Elements				Kinds of elements (max. 62)				Colors/Textures (max. 10)				Area
	Rej.	Vis. *	Tot*	Ma.*	Rej. **	Vis. **	Tot* *	Ma.* *	Rej.	Vis.	Tot.	Ma.	
Thomas 1 %	0 *0*	26 *100* *100*	26 *100*	26 *100*	0	11 *18*	11 *18*	11 *18*	0	7	7	7	34%
Thomas 2 %	1 *2*	39 *85* *87*	45 *98*	46 *100*	0	9 *15*	9 *15*	9 *15*	0	5	5	5	28%
June %	4 *6*	57 *80* *83*	69 *96*	72 *100*	4 *6*	20 *32*	20 *32*	24 *39*	1	7	7	8	31%
Wade %	7 *5*	81 *63* *66*	122 *95*	129 *100*	2 *3*	17 *27*	24 *39*	36 *42*	0	6	7	7	30%
Taylor %	9 *6*	118 *80* *84*	140 *95*	148 *100*	2 *3*	14 *23*	14 *23*	16 *26*	1	6	6	7	46%
Salvatore %	1 *3*	36 *100* *100*	36 *100*	36 *100*	1 *2*	13 *21*	13 *21*	14 *23*	0	4	4	4	19% *33***
Ming %	3 *4*	81 *96* *100*	81 *96*	84 *100*	0	17 *27*	17 *27*	17 *27*	0	6	6	6	31%
Pedro %	2 *2*	93 *76* *82*	120 *98*	122 *100*	0 *0*	13 *21*	16 *26*	16 *26*	0	8	8	8	51%
Ana	0	152	152	152	0	16	16	16	0	8	8	8	51%
%	*0*	*100* *100*	*100*	*100*		*26*	*26*	*26*					

* % of the total number of elements provided
** % of the total number of elements manipulated
* *Considering the mirror operation (see Salvatore's design process)

Table B.X
Graphic Protocol Analysis
Number of Elements of each Color/Texture

Color/textures	Th1	Th2	Jun	Wd	Tay	Sal	Min	Ped	Ana
red	2 ***7***	7 ***16***	5 ***7***		1 ***1***				
blue			2 ***3***		12 ***17***			20 ***17***	6 ***4***
green	1 ***3.5***	6 ***13***		7 ***6***		13 ***36***	14 ***17***		18 ***12***
black			5 ***5***	11 ***9***	36 ***26***		6 ***9***	5 ***42***	26 ***27***
white	1 ***3.5***	9 ***20***	9 ***13***	36 ***30***	18 ***13***	10 ***29***	24 ***29***	12 ***10***	10 ***7***
white brick	1 ***3.5***		15 ***21***	8 ***7***	15 ***11***			15 ***13***	17 ***11***
red brick	1 ***3.5***		6 ***9***	12 ***10***			8 ***10***	8 ***7***	27 ***18***
dark red (roof)		1 ***2***				4 ***12***	12 ***15***	32 ***27***	22 ***15***
gray (structure)	20 ***75***	22 ***49***	26 ***37***	41 ***34***	60 ***43***	8 ***23***	19 ***23***	28 ***23***	
hole and steps	1 ***3.5***								26 ***17***

* of the total number of elements in the drawing

TABLE B.XI
Graphic Protocol Analysis
Degree of repetition of Kinds of Elements, and Colors-Textures

	Elements / kinds of elements		Elements / Colors-Textures	
	Vis.	Used	Vis.	Used
Thomas 1	2.4	2.4	3.7	3.7
Thomas 2	4.3	5	7.8	9
June	2.9	3.5	8.1	9.9
Wade	4.8	5.1	13.5	17.4
Taylor	8.4	10	19.7	23.3
Salvatore	2.8 ***5.5***	2.8 ***5.5***	9 ***18***	9 ***18***
Ming	4.8	4.8	13.5	13.5
Pedro	7.2	7.5	13.3	15
Ana	9.5	9.5	19	19

TABLE XII
Visual Weight Indexes of the Color-Patterns

Color-pattern	Red	Green	Blue	y	w
Black	0	0	0	0	1
Dark Red Roof	26214	0	0	7838	0.880
Dark Gray Cornice-Connectors	8738	8738	8738	8738	0.866
Red Brick					0.775
Dark Red	26214	13107	0	7838	0.880
Black	0	0	0	0	1.000
Light Blue	0	13107	65535	15165	0.769
Dark Green	0	26214	0	15387	0.765
Red	65535	0	0	19595	0.701
Structural Gray	30583	30583	30583	34069	0.533
White Brick					0.535
Off-White	61166	61166	61166	61166	0.07
Black	0	0	0	0	1
Whitewash	61166	61166	61166	61166	0.07
White	65535	65535	65535	65535	0

TABLE XIII
Visual Weight Indexes of the Glazed Door and the Windows

Window	w
Black Windows	
Door	0.269
Big Rectangle	0.310
Small Rectangle	0.491
Big Square	0.360
Small Square	0.595
Green Windows	
Door	0.205
Big Rectangle	0.237
Small Rectangle	0.376
Big Square	0.275
Small Square	0.455

Window	w
Red Windows	
Door	0.188
Big Rectangle	0.240
Small Rectangle	0.344
Big Square	0.252
Small Square	0.417
Blue Windows	
Door	0.206
Big Rectangle	0.239
Small Rectangle	0.376
Big Square	0.279
Small Square	0.458

Appendix A.5

Calculation of the Vertical Reference and Compositional Axes of Wade's and Taylor's Designs

Calculus of the X Coordinate of the Mid-area and the Compositional Axes of Wade's Design

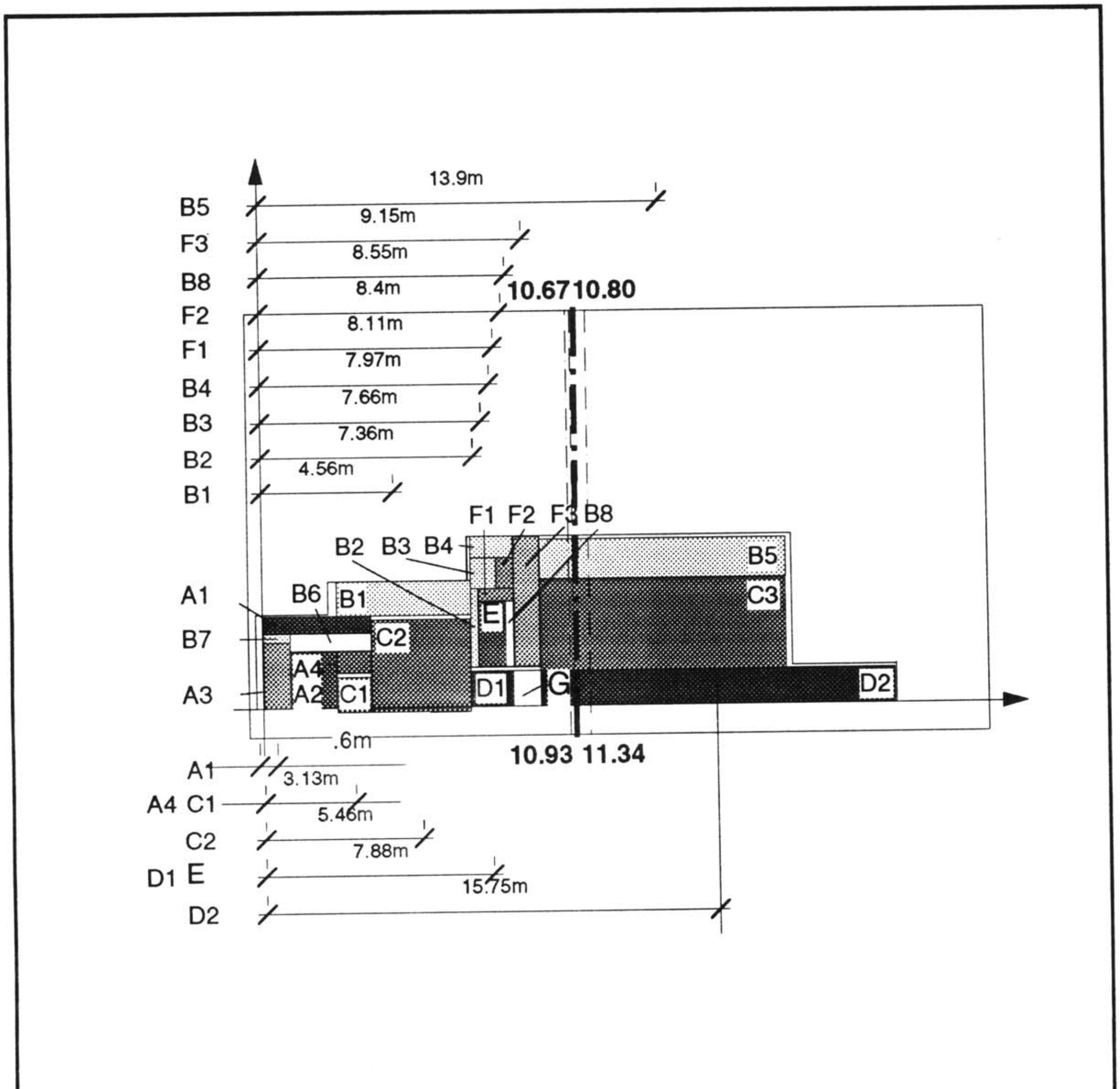


Fig. B.12
Measurements of Wade's
final design

TABLE B.5 - I

Calculus of the X Coordinate of the Compositional Axis of Wade's Design

	Areas An	Right Areas RAn	
A1	0.45 x 3.60		
A2	1.80 x 1.35		
A3	2.25 x 1.05		D2y + C3y + B5y =
A4	0.90 x 1.20		= 1.25 + 3.15 + 1.40 = 5.80
B1	1.20 x 4.60		
B2	2.70 x 0.30		93.724 /2 = 46.862
B3	1.05 x 0.90		
B4	0.75 x 1.50		54.130 - 46.862 = 7.268
B5	1.40 x 8.60	1.40 x 8.60	
B6	0.45 x 2.65		7.268 / 5.80 = 1.253
B7	0.30 x 1.05		
B8	2.25 x 0.30		A1x + C2x + D1x + F3x +
C1	0.9 x 1.05		+ 1.253 =
C2	3.15 x 3.55		3.60 + 3.55 + 1.50 + 0.90 +
C3	3.15 x 8.60	3.15 x 8.60	+ 1.253 = 10.803
D1	1.25 x 1.50		
D2	1.25 x 12.00	1.25 x 12.00	
E	2.25 x 0.90		
F1	0.45 x 1.20		
F2	1.05 x 0.60		
F3	4.50 x 0.90		
G	0.90 x 1.25		
SAn	93.724	54.13	

x coordinate = S wn An Dn / S wn An	**10.803**

TABLE B.5 - II

Calculus of the X Coordinate of the Compositional Axis of Wade's Design

(assuming that different colors have the same visual weight)

	Areas An	Colors-Patterns	Distances Dn	An Dn
A1	0.45 x 3.60	Black Glazing	1.80	2.916
A2	1.80 x 1.35	Ibidem	1.73	4.204
A3	2.25 x 1.05	Ibidem	0.53	1.252
A4	0.90 x 1.20	Ibidem	3.00	3.24
B1	1.20 x 4.60	Whitewash	4.56	25.171
B2	2.70 x 0.30	Ibidem	7.36	5.962
B3	1.05 x 0.90	Ibidem	7.66	7.239
B4	0.75 x 1.50	Ibidem	7.97	8.966
B5	1.40 x 8.60	Ibidem	13.90	167.356
B6	0.45 x 2.65	Ibidem	2.33	2.779
B7	0.30 x 1.05	Ibidem	0.53	0.167
B8	2.25 x 0.30	Ibidem	8.55	5.771
C1	0.9 x 1.05	White Brick	2.93	2.769
C2	3.15 x 3.55	Ibidem	5.46	61.056
C3	3.15 x 8.60	Ibidem	13.90	376.551
D1	1.25 x 1.50	Red Brick	7.88	14.775
D2	1.25 x 12.00	Ibidem	15.75	236.250
E	2.25 x 0.90	Dark Green	7.88	15.957
F1	0.45 x 1.20	Green Glazing	8.11	4.379
F2	1.05 x 0.60	Ibidem	8.40	5.292
F3	4.50 x 0.90	Ibidem	9.15	37.058
G	0.90 x 1.25	White	9.15	10.294
SAn	93.688	TOTAL		999.404

x coordinate = S wn An Dn / S wn An	**10.667**

TABLE B.5 - III

Calculus of the X Coordinate of the Compositional Axis of Wade's Design

(assuming that different colors have different visual weights measured against a white background)

	Areas An	Colors-Patterns	Color Weight In wn	Distances Dn	Visual Weight wn An Dn	wn An
A1	0.45 x 3.60	Black Glazing	0.635	1.80	1.851	1.029
A2	1.80 x 1.35	Ibidem	0.525	1.73	2.207	1.276
A3	2.25 x 1.05	Ibidem	0.276	0.53	0.346	0.652
A4	0.90 x 1.20	Ibidem	0.399	3.00	1.293	0.431
B1	1.20 x 4.60	Whitewash	0.066	4.56	1.661	0.364
B2	2.70 x 0.30	Ibidem	0.066	7.36	0.393	0.053
B3	1.05 x 0.90	Ibidem	0.066	7.66	0.478	0.062
B4	0.75 x 1.50	Ibidem	0.066	7.97	0.592	0.074
B5	1.40 x 8.60	Ibidem	0.066	13.90	11.045	0.795
B6	0.45 x 2.65	Ibidem	0.066	2.33	0.183	0.078
B7	0.30 x 1.05	Ibidem	0.066	0.53	0.011	0.021
B8	2.25 x 0.30	Ibidem	0.066	8.55	0.381	0.045
C1	0.9 x 1.05	White Brick	0.535	2.93	1.481	0.506
C2	**3.15 x 3.55**	**Ibidem**	**0.535**	**5.46**	**32.665**	**5.983**
C3	3.15 x 8.60	Ibidem	0.535	13.90	201.454	14.493
D1	1.25 x 1.50	Red Brick	0.775	7.88	11.541	1.453
D2	1.25 x 12.00	Ibidem	0.775	15.75	183.094	11.625
E	2.25 x 0.90	Dark Green	0.765	7.88	12.207	1.549
F1	0.45 x 1.20	Green Glazing	0.376	8.11	1.647	0.203
F2	1.05 x 0.60	Ibidem	0.376	8.40	1.990	0.237
F3	4.50 x 0.90	Ibidem	0.289	9.15	10.710	1.170
G	0.90 x 1.25	White	0.000	9.15	0.000	0.000
SAn	93.688	TOTAL			477.230	42.099

w average = S wn An / S An	**0.449**
x coordinate = S wn An Dn / S wn An	**11.336**

TABLE B.5 - IV

Calculus of the X Coordinate of the Compositional Axis of Wade's Design

(assuming that different colors have different visual weights measured against a background whose visual weight is the average of the visual weights of all the design's colors measured against a white background)

	Areas An	Colors-Patterns	Color Weight In wn	Distances Dn	Visual Weight wn An Dn	wn An
A1	0.45 x 3.60	Black Glazing	0.185	1.80	0.539	0.300
A2	1.80 x 1.35	Ibidem	0.075	1.73	0.315	0.182
A3	2.25 x 1.05	Ibidem	0.174	0.53	0.217	0.411
A4	0.90 x 1.20	Ibidem	0.051	3.00	0.165	0.055
B1	1.20 x 4.60	Whitewash	0.384	4.56	9.666	2.120
B2	2.70 x 0.30	Ibidem	0.384	7.36	2.289	0.311
B3	1.05 x 0.90	Ibidem	0.384	7.66	2.780	0.363
B4	0.75 x 1.50	Ibidem	0.384	7.97	3.443	0.432
B5	1.40 x 8.60	Ibidem	0.384	13.90	64.265	4.623
B6	0.45 x 2.65	Ibidem	0.384	2.33	1.067	0.458
B7	0.30 x 1.05	Ibidem	0.384	0.53	0.064	0.121
B8	2.25 x 0.30	Ibidem	0.384	8.55	2.216	0.259
C1	0.9 x 1.05	White Brick	0.085	2.93	0.235	0.080
C2	3.15 x 3.55	Ibidem	0.085	5.46	2.851	0.951
C3	3.15 x 8.60	Ibidem	0.085	13.90	32.007	2.303
D1	1.25 x 1.50	Red Brick	0.325	7.88	4.802	0.609
D2	1.25 x 12.00	Ibidem	0.325	15.75	76.781	4.875
E	2.25 x 0.90	Dark Green	0.315	7.88	5.026	0.638
F1	0.45 x 1.20	Green Glazing	0.074	8.11	0.324	0.040
F2	1.05 x 0.60	Ibidem	0.074	8.40	0.391	0.047
F3	4.50 x 0.90	Ibidem	0.164	9.15	19.919	0.664
G	0.90 x 1.25	White	0.450	9.15	6.077	0.506
SAn	93.724	TOTAL			222.492	20.348

x coordinate = wn An Dn / wn An	10.934

Calculus of the X Coordinate of the Mid-area and the Compositional Axes of Taylor's Design

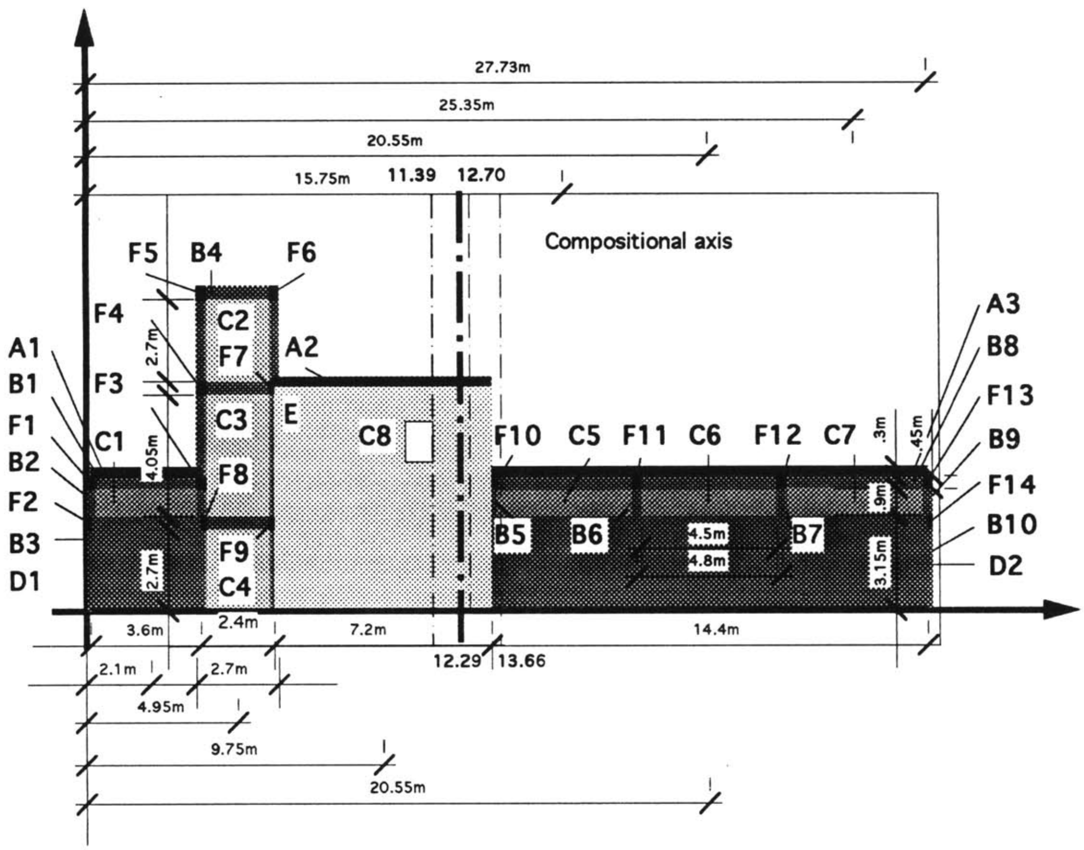


Fig. B.13
Measurements of Taylor's design

TABLE B.5 - V

Calculus of the X Coordinate of the Mid-Area Axis of Taylor's Design

	Areas An	Right Areas RAn	
A1	0.30 x 3.60		
A2	0.30 x 7.20		
A3	0.30 x 14.40	0.30 x 14.40	
B1	0.45 x 3.30		
B2	0.90 x 0.30		
B3	0.45 x 0.15		
B4	4 x 0.45 x 2.10 + 4.5 x 2.70 + 1.5 x 0.90 x 0.30 = 16.33		
B5	0.90 x 0.15	0.90 x 0.15	
B6	0.90 x 0.30	0.90 x 0.30	
B7	0.90 x 0.30	0.90 x 0.30	
B8	0.45x 8.10	0.45x 8.10	
B9	0.90 x 0.30	0.90 x 0.30	A2 h+ Eh =
B10	2.70 x 0.15	2.70 x 0.15	= 7.50 + 0.30 = 7.80
C1	0.90 x 4.50		
C2	2.70 x 2.10		165.348 / 2 = 82.674
C3	4.05 x 2.10		
C4	2.70 x 2.10		82.674 - 67.365 = 15.309
C5	0.90 x 4.50	0.90 x 4.50	
C6	0.90 x 4.50	0.90 x 4.50	15.309 / 7.80 = 1.963
C7	0.90 x 4.50	0.90 x 4.50	
C8	1.35 x 0.90		0.15 + 3.60 + 2.40 + 7.20 - 1.96 = 11.39
D1	3.15 x 3.60		
D2	3.15 x 14.40	3.15 x 14.40	
E	7.50 x 7.20		
F1	0.45 x 0.30		
F2	0.45 x 0.15		
F3	0.45 x 0.30		
F4	0.45 x 0.30		
F5	0.45 x 0.30		
F6	0.45 x 0.30		
F7	0.45 x 0.15		
F8	0.45 x 0.15		
F9	0.45 x 0.15		
F10	0.45 x 0.15	0.45 x 0.15	
F11	0.45 x 0.30	0.45 x 0.30	
F12	0.45 x 0.30	0.45 x 0.30	
F13	0.45 x 0.30	0.45 x 0.30	
F14	0.45 x 0.15	0.45 x 0.15	
S An	165.348	67.365	

X Coordinate = S wn An Dn / S wn An	**11.39**

TABLE B.5 - VI

Calculus of the X Coordinate of the Compositional Axis of Taylor's Design

(assuming that different colors have the same visual weight)

	Areas An	Colors-Patterns	Distances Dn	An Dn
A1	0.30 x 3.60	Cornice Gray	1.95	2.106
A2	0.30 x 7.20	Ibidem	9.75	21.060
A3	0.30 x 14.40	Ibidem	20.55	88.776
B1	0.45 x 3.30	Structural Gray	1.8	2.673
B2	0.90 x 0.30	Ibidem	0.15	0.041
B3	0.45 x 0.15	Ibidem	0.075	0.010
B4	4 x 0.45 x 2.10 + 4.5 x 2.70 + 1.5 x 0.90 x 0.30 = 16.33	Ibidem	4.95	80.833
B5	0.90 x 0.15	Ibidem	13.425	1.812
B6	0.90 x 0.30	Ibidem	18.15	4.901
B7	0.90 x 0.30	Ibidem	20.55	5.548
B8	0.45x 8.10	Ibidem	20.55	74.900
B9	0.90 x 0.30	Ibidem	27.75	7.492
B10	2.70 x 0.15	Ibidem	27.825	11.269
C1	0.90 x 4.50	Black Glazing	1.950	7.898
C2	2.70 x 2.10	Blue Glazing	4.950	28.067
C3	4.05 x 2.10	Ibidem	4.950	42.100
C4	2.70 x 2.10	Ibidem	4.950	28.067
C5	0.90 x 4.50	Black Glazing	15.750	63.788
C6	0.90 x 4.50	Ibidem	20.550	83.228
C7	0.90 x 4.50	Ibidem	25.350	94.568
C8	1.35 x 0.90	Red Glazing	10.950	18.954
D1	3.15 x 3.60	White Brick	1.950	22.113
D2	3.15 x 14.40	Ibidem	20.550	932.148
E	7.50 x 7.20	Whitewash	9.750	526.500
F1	0.45 x 0.30	Connector Gray	0.150	0.020
F2	0.45 x 0.15	Ibidem	0.075	0.005
F3	0.45 x 0.30	Ibidem	3.750	0.506
F4	0.45 x 0.30	Ibidem	3.750	0.506
F5	0.45 x 0.30	Ibidem	3.750	0.506
F6	0.45 x 0.30	Ibidem	6.150	0.830
F7	0.45 x 0.15	Ibidem	6.150	0.415
F8	0.45 x 0.15	Ibidem	3.750	0.253
F9	0.45 x 0.15	Ibidem	6.150	0.415
F10	0.45 x 0.15	Ibidem	13.425	0.906
F11	0.45 x 0.30	Ibidem	18.15	2.450
F12	0.45 x 0.30	Ibidem	20.55	0.375
F13	0.45 x 0.30	Ibidem	27.75	3.746
F14	0.45 x 0.15	Ibidem	27.825	1.878
S An	165.348	TOTAL (S)		2093.002

X Coordinate = S wn An Dn / S wn An	**12.658**

TABLE B.5 - VII

Calculus of the X Coordinate of the Compositional Axis of Taylor's Final Design

(assuming that different colors have different visual weight measured against a white background)

	Areas An	Colors-Patterns	Color Weight In wn	Distances Dn	Visual Weight wn An Dn	wn An
A1	0.30 x 3.60	Cornice Gray	0.866	1.95	1.824	0.935
A2	0.30 x 7.20	Ibidem	0.866	9.75	18.238	1.870
A3	0.30 x 14.40	Ibidem	0.866	20.55	76.880	3.741
B1	0.45 x 3.30	Structural Gray	0.533	1.8	1.425	0.792
B2	0.90 x 0.30	Ibidem	0.533	0.15	0.022	0.144
B3	0.45 x 0.15	Ibidem	0.533	0.075	0.003	0.036
B4	4 x 0.45 x 2.10 + 4.5 x 2.70 + 1.5 x 0.90 x 0.30 = 16.33	Ibidem	0.533	4.95	43.095	8.706
B5	0.90 x 0.15	Ibidem	0.533	13.425	0.966	0.072
B6	0.90 x 0.30	Ibidem	0.533	18.15	2.612	0.144
B7	0.90 x 0.30	Ibidem	0.533	20.55	2.957	0.144
B8	0.45x 8.10	Ibidem	0.533	20.55	39.924	1.943
B9	0.90 x 0.30	Ibidem	0.533	27.75	3.994	0.144
B10	2.70 x 0.15	Ibidem	0.533	27.825	6.006	0.216
C1	0.90 x 4.50	Black Glazing	0.312	1.950	2.464	1.264
C2	2.70 x 2.10	Blue Glazing	0.164	4.950	4.603	0.930
C3	4.05 x 2.10	Ibidem	0.164	4.950	6.904	1.395
C4	2.70 x 2.10	Ibidem	0.164	4.950	4.603	0.930
C5	0.90 x 4.50	Black Glazing	0.312	15.750	19.902	1.264
C6	0.90 x 4.50	Ibidem	0.312	20.550	25.967	1.264
C7	0.90 x 4.50	Ibidem	0.312	25.350	32.032	1.264
C8	1.35 x 0.90	Red Glazing	0.245	10.950	3.260	0.298
D1	3.15 x 3.60	White Brick	0.535	1.950	11.830	6.067
D2	3.15 x 14.40	Ibidem	0.535	20.550	498.699	24.268
E	7.50 x 7.20	Whitewash	0.066	9.750	34.749	3.564
F1	0.45 x 0.30	Connector Gray	0.866	0.150	0.018	0.117
F2	0.45 x 0.15	Ibidem	0.866	0.075	0.004	0.058
F3	0.45 x 0.30	Ibidem	0.866	3.750	0.438	0.117
F4	0.45 x 0.30	Ibidem	0.866	3.750	0.438	0.117
F5	0.45 x 0.30	Ibidem	0.866	3.750	0.438	0.117
F6	0.45 x 0.30	Ibidem	0.866	6.150	0.719	0.117
F7	0.45 x 0.15	Ibidem	0.866	6.150	0.359	0.058
F8	0.45 x 0.15	Ibidem	0.866	3.750	0.219	0.058
F9	0.45 x 0.15	Ibidem	0.866	6.150	0.359	0.058
F10	0.45 x 0.15	Ibidem	0.866	13.425	0.785	0.058
F11	0.45 x 0.30	Ibidem	0.866	18.15	2.122	0.117
F12	0.45 x 0.30	Ibidem	0.866	20.55	2.403	0.117
F13	0.45 x 0.30	Ibidem	0.866	27.75	3.244	0.117
F14	0.45 x 0.15	Ibidem	0.866	27.825	1.627	0.058
S An	165.348	TOTAL (S)			856.132	62.679

W average = S w An / S An	0.380
X Coordinate = S wn An Dn / S wn An	**13.659**

TABLE B.5 - VIII

Calculus of the X Coordinate of the Compositional Axis of Taylor's Final Design

(assuming that different colors have different visual weights
measured against a background whose visual weight is the average of the visual weights of all
the design's colors measured against a white background)

	Areas An	Colors-Patterns	Color Weight In wn	Distances Dn	Visual Weight wn An Dn	wn An
A1	0.30 x 3.60	Cornice Gray	0.486	1.95	1.024	0.525
A2	0.30 x 7.20	Ibidem	0.486	9.75	10.235	1.050
A3	0.30 x 14.40	Ibidem	0.486	20.55	43.145	2.099
B1	0.45 x 3.30	Structural Gray	0.153	1.8	0.409	0.227
B2	0.90 x 0.30	Ibidem	0.153	0.15	0.006	0.041
B3	0.45 x 0.15	Ibidem	0.153	0.075	0.001	0.010
B4	4 x 0.45 x 2.10 + 4.5 x 2.70 + 1.5 x 0.90 x 0.30 = 16.33	Ibidem	0.153	4.95	11.243	2.498
B5	0.90 x 0.15	Ibidem	0.153	13.425	0.277	0.021
B6	0.90 x 0.30	Ibidem	0.153	18.15	0.750	0.041
B7	0.90 x 0.30	Ibidem	0.153	20.55	0.849	0.041
B8	0.45x 8.10	Ibidem	0.153	20.55	11.460	0.558
B9	0.90 x 0.30	Ibidem	0.153	27.75	1.146	0.041
B10	2.70 x 0.15	Ibidem	0.153	27.825	1.724	0.062
C1	0.90 x 4.50	Black Glazing	0.068	1.950	0.054	0.028
C2	2.70 x 2.10	Blue Glazing	0.216	4.950	6.063	1.225
C3	4.05 x 2.10	Ibidem	0.216	4.950	9.094	1.837
C4	2.70 x 2.10	Ibidem	0.216	4.950	6.062	1.225
C5	0.90 x 4.50	Black Glazing	0.068	15.750	0.434	0.028
C6	0.90 x 4.50	Ibidem	0.068	20.550	0.566	0.028
C7	0.90 x 4.50	Ibidem	0.068	25.350	0.698	0.028
C8	1.35 x 0.90	Red Glazing	0.140	10.950	1.863	0.170
D1	3.15 x 3.60	White Brick	0.331	1.950	7.320	3.754
D2	3.15 x 14.40	Ibidem	0.331	20.550	308.541	15.014
E	7.50 x 7.20	Whitewash	0.314	9.750	165.321	16.956
F1	0.45 x 0.30	Connector Gray	0.486	0.150	0.010	0.066
F2	0.45 x 0.15	Ibidem	0.486	0.075	0.005	0.068
F3	0.45 x 0.30	Ibidem	0.486	3.750	0.123	0.033
F4	0.45 x 0.30	Ibidem	0.486	3.750	0.246	0.066
F5	0.45 x 0.30	Ibidem	0.486	3.750	0.246	0.066
F6	0.45 x 0.30	Ibidem	0.486	6.150	0.404	0.066
F7	0.45 x 0.15	Ibidem	0.486	6.150	0.202	0.033
F8	0.45 x 0.15	Ibidem	0.486	3.750	0.123	0.033
F9	0.45 x 0.15	Ibidem	0.486	6.150	0.202	0.033
F10	0.45 x 0.15	Ibidem	0.486	13.425	0.440	0.033
F11	0.45 x 0.30	Ibidem	0.486	18.15	0.595	0.033
F12	0.45 x 0.30	Ibidem	0.486	20.55	1.348	0.066
F13	0.45 x 0.30	Ibidem	0.486	27.75	0.910	0.066
F14	0.45 x 0.15	Ibidem	0.486	27.825	0.913	0.033
SAn	165.15	TOTAL (S)			593.06	48.306

X Coordinate = S wn An Dn / S wn An	12.293

Appendix B.6

Ana's Design Process Rules and Search Tree

Ana's design process paradigms and rules

Paradigms

1st Paradigms: the Back Bay, Beacon Street, her own house.
2nd Paradigm: a fisherman's village in Portugal.

Rules

The rules are organized chronologically, except rules 23 (diversity) and 24 (order) that are presented at the end, since they were defined progressively.

Rule 1- Start building the houses from the ground level.

Rule 2 - The facades should be attached (as there are no trees it would look a little bit desolated if empty spaces were left between the houses).

Rule 3 - The facades should be not very tall (to make the design faster).

Rule 4 - The facades should be of only one color.

Rule 5 - The structure is not be seen.

Rule 6 - The doors shouldn't be at the ground level.

Rule 7 - The small panels at the bottom and big panels at the top (because we can distinguish the lines that divide the different panels).

Rule 8 - The windows and door should be placed after the wall panels (there must be a panel behind a door, because the doors are narrower).

Rule 9 - The windows should be placed after the door.

Rule 10 - The windows cannot not be attached to the door.

Rule 11 - Both the windows and the door cannot be placed on the side panels of a house.

Rule 12 - Each house should have a door (to come in) and a window (to enter light).

a) If the house does not have a window it should have a glazed door (to enter light).

b) A house has to have at least one door (to come in).

c) If the house has two doors, one of the doors is a glazed door (to enter light).

d) All the opaque doors have a window.

Rule 13 - If the house has two doors, they cannot be attached to each other.

Rule 14 - The distance between two doors, or a door and a window of the same house cannot be larger than one panel.

Rule 15 - A house should be five panels long (from rules 11,12, 13 and 14).

a) If the house has only a door, it sould be 3 panels long.

b) A house is at the utmost six panels long.

Rule 16 - The doors and windows of each house should be of the same color.

Rule 17 - Both second floors will be on the left.

Rule 18 - For a matter of perspective, the windows on the second floor cannot be taller than the windows on the first floor (rule not respected).

Rule 19 - All the doors have steps (from rule 6).

Rule 20 - All the houses will have a cornice.

Rule 21 - The windows shouldn't have a unique glass.

Rule 22 - The glass doors shouldn't have a unique glass (a child could break it).

Rule 23 - Diversity

Diversity requires contrast:

ex.: 'An opaque door because the previous is a glazed one.'

Diversity has to have a limit:

ex.: 'In the same facade I am not going to paint the windows with different colors.'

Diversity has to have a certain coherence (logic):

ex.: 'Glass doors because the environment requires light and the climate allows it.'

Rule 24 - Balance

Table B.XIV
Universe of Attributes and Values of Ana's design
(see also Fig. 7.99)

Element		Attributes	Values
HOUSE	**Grounding**	grounding	0, 1
		grounding position	x (0) y (0)
		grounding height	*1,2,3,4*
		grounding width	*1,2,3,4*,5,6,... panel
		grounding color	red brick, white brick, whitewash
	Stairs		
	Floor	floor number	0,1,3,4
		floor position	x (1,2,3,... panels) y (1, *1 1/5 , 1 1/4, 1 1/3 ,...* panels)
		wall height	1, *1 1/5 , 1 1/4, 1 1/3* panel =3.15m
		wall width	3,4,5,6, *7,8,...* panel =1.20m
		wall color	red brick, white brick, whitewash
	Door	door position (on the floor)	left *(1*,2,3,4,... *panel)* right *(*n-1, *n-2,... panel)*
		door position (on the panel)	x (1,*2,3*) y (1,2,3,4,5,6,7,... n x 0.15m)
		door shape	big rectangle
		door type	glazed, opaque
		door color	green, blue, black, *red*
		door detail	None, 1.1, 1.2, *1.3,...,2,...,3,...,4,...,5,...* (see Fig. 7.99)
		door expansion	None, 1.1, *1.2, 1.3,...,2,...,3,...,4,...,5,...* (see Fig. 7.99)
	Window	window position (on the floor)	x (*1*, 2, 3, 4, *5, 6, 7, 8,...* panel) y (*1*,2,3,4,5,*6,7,8...*)
		window shape	big rectangle, medium square, *medium rectangle, small vertical rectangle, small horizontal rectangle, small square window*
		window color	green, blue, black, (red)
		window detail	None, 1.1, 1.2, *1.3,...,2,...,3,...,4,...,5,...* (see Fig. 7.99)
		window expansion	None, 1.1, *1.2, 1.3,...,2,...,3,...,4,...,5,...* (see Fig. 7.99)
	Cornice	cornice	0,1
		cornice position	x (1,2,3,... panels) y (1, *1 1/5 , 1 1/4, 1 1/3 ,...* panels)
		cornice height	1.1,*1.2,1.3, 1.4,...,2.1, 2.2, 2.3,2.4,...* panel
		cornice width	*1,2,3,4*,5,6,... panel
		cornice color	black, *red brick, white brick, whitewash*
	Roof	roof	0,1
		roof position	x (1,2,3,... panels) y (1, *1 1/5 , 1 1/4, 1 1/3 ,...* panels)
		roof height	1,*2,3 ,...* panel
		roof width	*1,2,3,4*,5,6,... panel
		roof color	dark red

Note: The values used by Ana in her design are shown in normal style, other values are shown in *italics*

Table B.XV
Attributes and values of Ana's design
Superstructure

Attributes	House 1	House 2	House 3	House 4	House 5
Grounding	1	1	1	1	1
grounding position x	0	6	11	17	23
grounding position y	0	0	0	0	0
grounding height	3	3	3	3	3
grounding width	5	5	6	5	?
grounding color	RedBrick	WhiteBrick	RedBrick	WhiteWash	WhiteBrick
1st floor	1	1	1	1	1
wall position x	0	6	11	17	23
wall position y	1//3	1//3	1//3	1//3	1//3
wall height	1	1	1	1	1
wall size	5	5	6	5	?
wall color	RedBrick	WhiteBrick	RedBrick	WhiteWash	WhiteBrick
number of doors	1	2	1	1	?
number of windows	1	-	2	1	?
2nd floor	1	1	0	0	0
wall position x (on the floor)	0	6	11	17	23
wall position y (on the floor)	11/3	11/3	-	-	-
wall height	1	1	-	-	-
wall size	5	5	-	-	-
wall color	RedBrick	WhiteBrick	-	-	-
number of windows	2	3	-	-	-
Cornice	1	1	1	1	1
cornice position x	0	6	11	17	23
cornice position y	2 1/3	2 1/3	1 1/3	1 1/3	1 1/3
cornice height	3	3	3	3	3
cornice width	5	5	6	5	?
cornice color	RedBrick	WhiteBrick	RedBrick	WhiteWash	WhiteBrick
Roof	1	1	1	1	1
roof position x	0	6	11	17	23
roof position y	2 2/3	2 2/3	1 1/3	1 2/3	1 2/3
roof height	1	1	1	1	1
roof width	5	5	6	5	?
roof color	Dark red	Dark red	Dark red	Dark red	Dark red

Table B.XV
Attributes and values of Ana's design
Openings
(continued)

Attributes	House 1	House 2	House 3	House 4	House 5
1st Floor					
Doors					
door position Left	4	2 4	5	2	?
(on the floor) Right	2	4 2	2	4	?
door position x	2	2 3	3	2	?
(on the panel) y	4	5 5	6	6	?
door shape	BR	BR	BR	BR	BR
door type	Glaz.	Opaq.	Glaz.	Opaq.	?
door color	Green	Blue	Black	Green	?
door detail	MRW	MSW	MRW	MSW	?
Windows					
window position Left	2	-	2 3	4	?
(on the floor) Right	4	-	5 4	2	?
window position x	2	-	3 3	3	?
(on the floor) y	4	-	6 6	6	?
window shape	MR	-	MR MR	MR	?
window color	Green	-	Black Black	Green	?
window detail	3R	-	- -	-	?
window expansion	-	-	- -	T R	?
2nd Floor					
window position left	2	1.5 2.5	-	-	-
window position right	4	3.5 4.5	-	-	-
window position x	2	2 3	-	-	-
window positions y	4	5 6	-	-	-
window type	MR SQ	MR SQ	- -	- -	? ?
window color	Green Green	Blue Blue	- -	- -	? ?
window detail	- -	- -	- -	- -	? ?
window expansion	RLT T	D -	- -	- -	? ?

Table B.XVI
Horizontal Sequences
Attribute and Sequence Repetition Degrees
Superstructure

Degree of Attribute Repetition (Dr_a) Relative	Abs.	r_s	Attributes	House 1	House 2	House 3	House 4	House 5
(5 - 1) / 5 = 0.80	1.00	A	**Grounding**	a	a	a	a	a
(5 - 1) / 5 = 0.80	1.00	A	grounding position x	a	a	a	a	a
(5 - 1) / 5 = 0.80	1.00	A	grounding position y	a	a	a	a	a
(5 - 1) / 5 = 0.80	1.00	A	grounding height	a	a	a	a	a
(4 -2) / 4 = 0.50	0.66	B	grounding width	a	a	b	a	?
(5 - 3) / 5 = 0.40	0.50	C	grounding color	a	b	a	c	b
(5 - 1) / 5 = 0.80	1.00	A	**1st floor**	a	a	a	a	a
(5 - 5) / 5 = 0.00	0.00	D	wall position x	a	b	c	d	e
(5 - 1) / 5 = 0.80	1.00	A	wall position y	a	a	a	a	a
(5 - 1) / 5 = 0.80	1.00	A	wall height	a	a	a	a	a
(4 -2) / 4 = 0.50	0.66	B	wall width	a	a	b	a	?
(5 - 3) / 5 = 0.40	0.50	C	wall color	a	b	a	c	b
(4 - 3) / 4 = 0.25	0.33	E	number of doors	a	b	c	a	?
(4 - 2) / 4 = 0.50	0.66	F	number of wind	a	b	a	a	?
(5 - 2) / 5 = 0.60	0.75	**G**	**2nd floor**	a	a	b	b	b
(2 - 2) / 2 = 0.00	0.00	C	wall position x	a	b	-	-	-
(2 - 1) / 2 = 0.50	0.50	A	wall position y	a	a	-	-	-
(2 - 1) / 2 = 0.50	1.00	A	wall height	a	a	-	-	-
(2 - 1) / 2 = 0.50	1.00	A	wall width	a	a	-	-	-
(2 - 2) / 2 = 0.00	0.00	C	wall color	a	b	-	-	-
(2 - 2) / 2 = 0.00	0.00	**C**	number of wind	a	b	-	-	-
(5 - 1) / 5 = 0.20	0.25	***A***	**Cornice**	a	a	a	a	a
(5 - 5) / 5 = 0.00	0.00	D	cornice position x	a	b	c	d	e
(5 - 2) / 5 = 0.60	0.75	H	cornice position y	a	a	b	b	b
(5 - 1) / 5 = 0.80	1.00	A	cornice height	a	a	a	a	a
(5 - 1) / 5 = 0.80	1.00	A	cornice width	a	a	a	a	a
(5 - 1) / 5 = 0.80	1.00	A	cornice color	a	a	a	a	a
(5 - 1) / 5 = 0.80	1.00	**A**	**Roof**	a	a	a	a	a
(5 - 5) / 5 = 0.00	0.00	D	roof position x	a	b	c	d	e
(5 - 2) / 5 = 0.60	0.75	G	roof position y	a	a	b	b	b
(5 - 1) / 5 = 0.80	0.75	A	roof height	a	a	a	a	a
(5 - 1) / 5 = 0.80	0.75	A	roof width	a	a	a	a	a
(5 - 1) / 5 = 0.80	0.75	A	roof color	a	a	a	a	a

Average Relative Degrees of Depetition for the Horizontal Sequences (superstructure)	
Dr_a	0.65
Dr_s	(33 - 8) / 33 = 0.76
Dr	0.71

Table B.XVI
Horizontal Sequences
Attribute and Sequence Repetition Degrees
Openings
(continued)

Degree of Attribute Repetition (Dra)		S	Attributes	House 1	House 2	House 3	House 4	House 5
Relative	**Abs.**							
1st Floor								
Doors								
(5 - 3) / 5 = 0.40	0.50	*A*	door position left	a	b a	c	b	?
(5 -2) / 5 = 0.60	0.75	*B*	door position right	a	b a	a	b	?
(5 -2) / 5 = 0.60	0.75	*C*	door position x	a	a b	b	a	?
(5 - 3) / 5 = 0.40	0.50	*D*	door position y	a	b b	c	c	?
(5 - 1) / 5 = 0.80	1.00	*E*	door shape	a	a a	a	a	?
(4 -2) / 4 = 0.50	0.66	*F*	door type	a	a b	a	b	?
(4 -3) / 4 = 0.25	0.33	*G*	door color	a	a b	c	a	?
(4 -2) / 4 = 0.50	0.66	*F*	door detail	a	a b	a	b	?
windows								
(5 - 4) / 5 = 0.20	0.25	*H*	wind position left	a	b	a c	d	?
(5 - 3) / 5 = 0.40	0.50	*I*	wind position right	a	b	c c	c	?
(5 - 3) / 5 = 0.40	0.50	*I*	wind position x	a	b	c c	c	?
(5 - 3) / 5 = 0.40	0.50	*I*	wind position y	a	b	c c	c	?
(4 -2) / 4 = 0.50	0.66	*J*	window shape	a	b	a a	a	?
(4 -3) / 4 = 0.25	0.33	*K*	window color	a	b	c c	a	?
(4 -2) / 4 = 0.50	0.66	*L*	window detail	a	b	b b	b	?
(4 -3) / 4 = 0.50	0.66	*M*	window expansion	a	a	a a	b	?
2nd Floor								
windows								
(5 - 4) / 5 = 0.20	0.25	*N*	wind position left	a b	c d b	-	-	?
(5 - 4) / 5 = 0.20	0.25	*N*	wind position right	a b	c d b	-	-	?
(5 - 2) / 5 = 0.60	0.75	*M*	wind position x	a a	b b b	-	-	?
(5 - 3) / 5 = 0.40	0.50	*O*	wind position y	a a	b b c	-	-	?
(4 - 2) / 4 = 0.50	0.66	*P*	window shape	a a	a b	-	-	?
(4 - 2) / 4 = 0.50	0.66	*L*	window color	a a	b b	-	-	?
(4 - 1) / 4 = 0.75	1.00	*Q*	window detail	a a	a a	-	-	?
(4 - 4) / 4 = 0.00	0.00	*R*	window expansion	a b	c d	-	-	?

Average Relative Degrees of Repetition for the Horizontal Sequences (openings)	
Dr_a	0.55
Dr_s	(24 - 18) / 24 = 0.25
Dr	0.40

Average Relative Degrees of Repetition for the Horizontal Sequences (by degree)	
Dr_a	0.55 + 0.65 = 0.60
Dr_s	0.25 + 0.76 = 0.51
Dr	0.40 + 0.71 = 0.56

Table B.XVIII
Vertical Sequences
Sequence Repetition Degrees
Superstructure

Attribute	House 1						House 2						House 3						House 4						House 5					
Sequen.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Ground.	a						a						a						a						a					
position x		a						a						a						a						a				
position y			a						a						a						a						a			
height				a						a						a						a						a		
width					a						a						a						a						a	
color						a						a						a						a						a
1st floor	a						a						a						a						a					
position x		a						a						a						a						a				
position y			b						b						b						b						b			
height				b						b						b						b						b		
width					a						a						a						a						a	
color						a						a						a						a						a
2nd floor	a						a						b						b						b					
position x		a						a						-						-						-				
position y			c						c						-						-						-			
height				b						b						-						-						-		
width					a						a						-						-						-	
color						a						a						-						-						-
Cornice	a						a						a						a						a					
position x		a						a						a						a						a				
position y			d						d						c						c						c			
height				c						c						c						c						c		
width					a						a						a						a						a	
color						b						b						b						b						b
Roof	a						a						a						a						a					
position x		a						a						a						a						a				
position y			e						e						d						d						d			
height				d						d						d						d						d		
width					a						a						a						a						a	
color						c						c						c						c						c
Drs = (30 - 6) / 30 = 0.8	A	A	B	C	A	D	A	A	B	C	A	D	E	A	B	B	A	F	E	A	B	B	A	F	E	A	B	B	A	F

Table B.XVII
Vertical Sequences
Attribute Repetition Degrees
Superstructure
(continued)

Sequence	Dr_a relative	Dr_a absolute
1	(5 - 1) / 5 = 0.80	1.00
2	(5 - 1) / 5 = 0.80	1.00
3	(5 - 5) / 5 = 0.00	0.00
4	(5 - 4) / 5 = 0.20	0.25
5	(5 - 1) / 5 = 0.80	1.00
6	(5 - 3) / 5 = 0.40	0.50
7	(5 - 1) / 5 = 0.80	1.00
8	(5 - 1) / 5 = 0.80	1.00
9	(5 - 5) / 5 = 0.00	0.00
10	(5 - 4) / 5 = 0.20	0.25
11	(5 - 1) / 5 = 0.80	1.00
12	(5 - 3) / 5 = 0.40	0.50
13	(5 - 2) / 5 = 0.60	0.75
14	(4 - 1) / 4 = 0.75	1.00
15	(4 - 4) / 4 = 0.00	0.00
16	(4 - 4) / 4 = 0.00	0.00
17	(4 - 1) / 4 = 0.75	1.00
18	(4 - 3) / 4 = 0.25	0.33
19	(5 - 2) / 5 = 0.60	0.75
20	(4 - 1) / 4 = 0.75	1.00
21	(4 - 4) / 4 = 0.00	0.00
22	(4 - 4) / 4 = 0.00	0.00
23	(4 - 1) / 4 = 0.75	1.00
24	(4 - 3) / 4 = 0.25	0.33
25	(5 - 2) / 5 = 0.60	0.75
26	(4 - 1) / 4 = 0.75	1.00
27	(4 - 4) / 4 = 0.00	0.00
28	(4 - 4) / 4 = 0.00	0.00
29	(4 - 1) / 4 = 0.75	1.00
30	(4 - 3) / 4 = 0.25	0.33
Average	0.44	0.56

Average Relative Degrees of Depetition for the Vertical Sequences (superstructure)	
Dr_a	0.44
Dr_s	0.80
Dr	**0.62**

Table B.XVII
Vertical Sequences
Sequence Repetition Degrees
Openings

House	House 1																			
Opening	1										2									
Sequen.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1st floor																				
opening	a										a									
position left		a										a								
position right			a										a							
position x				a										a						
position y					a										a					
shape						a										a				
type							a										a			
color								a										a		
detail									a										a	
expansion										a										a
2nd floor																				
opening	a										a									
position left		a										a								
position right			a										a							
position x				a										a						
position y					a										a					
shape						a										b				
type							a										a			
color								a										a		
detail									b										b	
expansion										b										a
	A	A	A	A	A	A	A	A	B	B	A	A	A	A	A	B	A	A	B	A
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.50	0.00

Table B.XVII
Vertical Sequences
Sequence Repetition Degrees
(continued)

House	**House 2**																			
Opening	3										4									
Sequen.	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1st floor																				
opening	a										a									
position left		a										a								
position right			a										a							
position x				a										a						
position y					a										a					
shape						a										a				
type							a										a			
color								a										a		
detail									a										a	
expansion										a										a
2nd floor																				
opening	a										a									
position left		a										a								
position right			a										a							
position x				b										a						
position y					b										b					
shape						b										b				
type							a										b			
color								a										a		
detail									a										a	
expansion										a										a
	A	A	A	B	B	B	A	A	A	A	A	A	A	A	B	B	B	A	A	A
	0.00	0.00	0.00	0.50	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.50	0.50	0.00	0.00	0.00

House 3 and House 4	5 x 9 sequences A = 45 45 x (Dra = 0.00) = 0.00

Average Degrees of Repetition for the Vertical Sequences (openings)	
Dr_a	(75 x 0.00 + 10 x 0.50) / 85 = 0.06
Dr_s	(65 - 2) / 65 = 0.97
Dr	(0.97 + 0.06) / 2 = 0.52

Average Dr for the Vertical Sequences	
Dr_a	(0.44 +).06) / 2 = 0.25
Dr_s	(0.80 + 0.97) / 2 = 0.89
Dr	0.57

Appendix C

Formulas

I
Horizontal Visual Balance
Average Top Height formula

$$h_{ay} = \frac{y_1 x_1 + y_2 x_2 + \ldots + y_n x_n}{x_1 + x_2 + \ldots + x_n}$$

y_n - height of the top boundary of element n
x_n - width of the element n

II
Horizontal Visual Balance
Average Bottom Height Formula

$$h_{ay'} = \frac{y'_1 x_1 + y'_2 x_2 + \ldots + y'_n x_n}{x_1 + x_2 + \ldots + x_n}$$

y'_n - height of the bottom boundary of element n
x_n - width of element n

III
Horizontal Visual Balance
Average Height Formula

$$h_a = \frac{(y_1+y_1')x_1 + (y_2+y_2')x_2 + \ldots + (y_n+y_n')\, x_n}{2(x_1 + x_2 + \ldots + x_n)}$$

y_n - height of the bottom boundary of element n
y'_n - height of the bottom boundary of element n
x_n - width of element n

I V
Gray Index

$y = 0.299\ R + 0.587\ G + 0.114\ B$

y - White Index
R - Red
G - Green
B - Blue

V
Color Weight Index Formula

$$w = \frac{65535 - y}{65535}$$

w - Color Weighting Index
y - White Index

VI
Vertical Visual Balance Formula

$$x = \frac{(w_1 - w_b)^* A_1 D_1 + (w_2 - w_b)^* A_2 D_2 + \ldots + (w_n - w_b)^* A_n D_n}{(w_1 - w_b)^* A_1 + (w_2 - w_b)^* A_2 + \ldots + (w_n - w_b)^* A_n}$$

x - x coordinate of the compositional balance axis
$w_{1...b}$ - Color Weight Indexes of each shape color
w_b - Color Weight Indexes of the background
A - Area of the shape
D - Distance of the shape center to the origin
*(wn - wb) - Color weight of the shape relatively to the background if wn>wb
*(wb - wn) - Color weight of the shape relatively to the background if wb>wn

VII

TABLE I
RGB and Color Weight Index Values for the Principal Colors

	Red	Green	Blue	Hue	Saturation	Brightness	w
White	65535	65535	65535	0	0	65535	0
Yellow	65535	65535	0	10922	65535	65535	0.114
Green	0	65535	0	21845	65535	65535	0.413
Cyan		65535	65535	32767	65535	65535	0.299
Blue	0	0	65535	43690	65535	65535	0.886
Magenta	65535		65535	54612	65535	65535	0.587
Red	65535	0	0	65535	65535	65535	0.701
Black	0	0	0	0	0	0	1

VIII
Degree of Attribute Repetition

$$dr_a = \frac{\text{Total number of shapes s - Total number of different values a}}{\text{Total number of shapes s}}$$

dr_a - degree of attribute *a* repetition

IX
Degree of Sequence Repetition

$$dr_s = \frac{\text{Total of number sequences - Total number of different sequences}}{\text{Total number of sequences}}$$

dr_s - degree of sequence repetition

Sources of Illustrations

All the illustrations otherwise indicated below are by the author.

Section 2

Fig. 2.4
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Fig. 9.1
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Fig. 9.4
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Black and white version of color photographs

Fig. 2.1
Obidos, Portugal
Traditional settlement

Fig. 2.2
Portugal, 1980s
Informal settlement

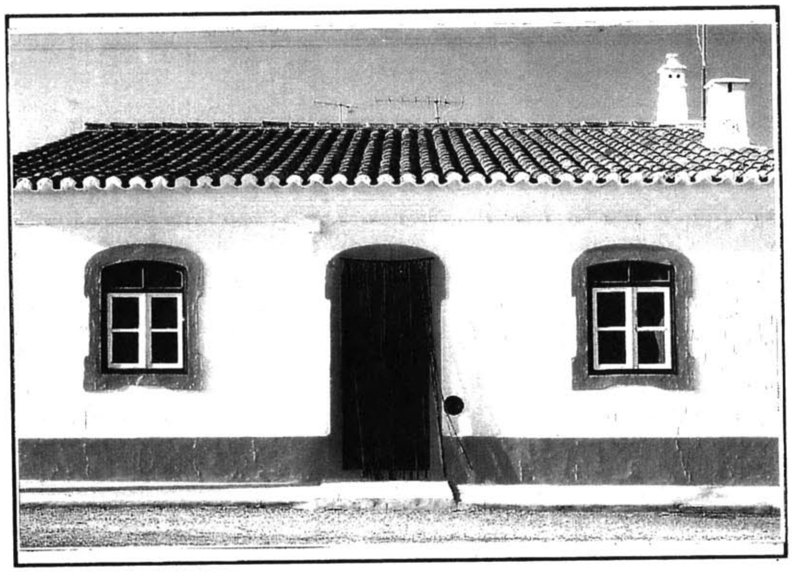


Fig. 7.53
Ana's paradigms: The Back Bay, in Boston (USA) and a fisherman's village in Portugal

panel behind the door? The door is smaller... ***I am influenced by the building*** *where I live. A door and a window.*

Later on, when she realized that she could not achieve the same degree of decoration of her initial paradigm she shifted her paradigm:

> *And now a window. I am going to make it fancier. No...In this I am going to put some decoration, but later... I think that my Beacon St. is going to change to a fishermen's neighborhood.*

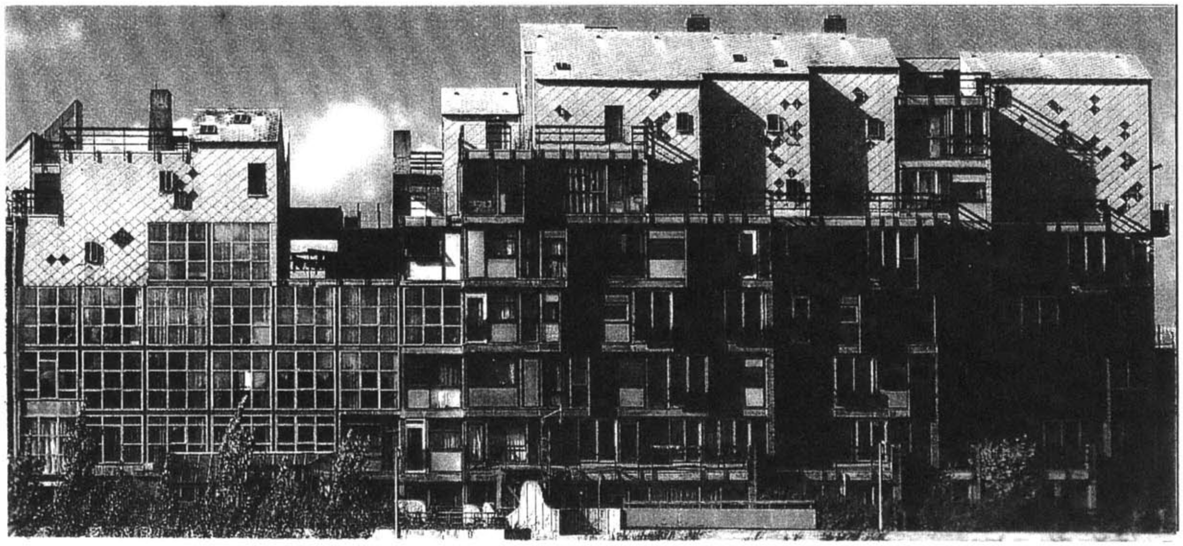


Fig. 7.73
Lucien Kroll, 1971
Sudent dormitory, University of Lovaina, Belgium

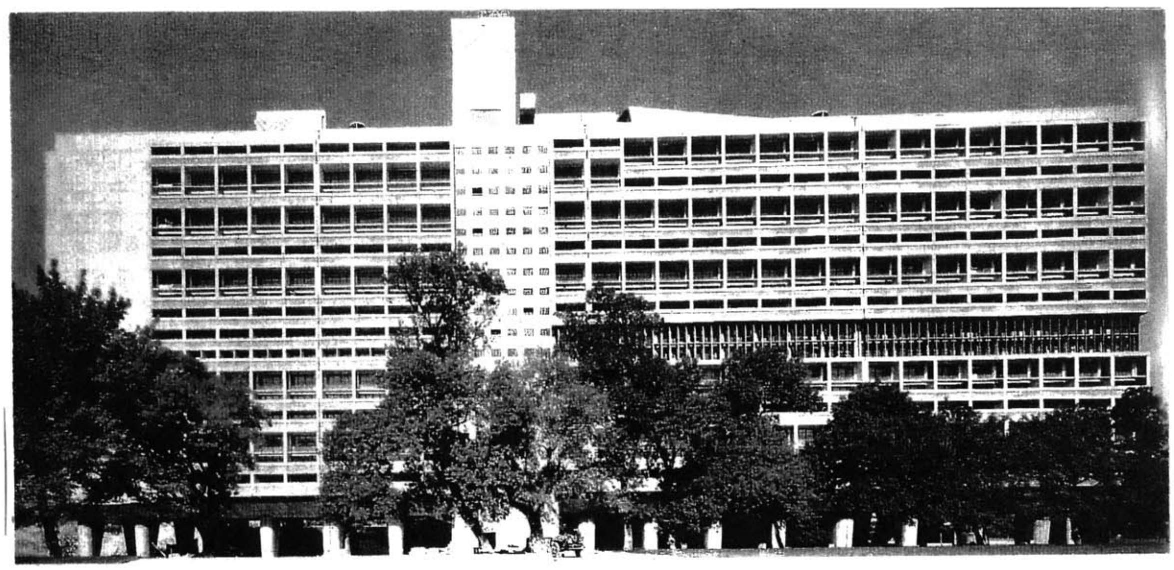
Fig. 7.74
The Back Bay, turn of century, Boston

In the dormitory, Kroll tried to express the individuality of the diverse students through its layout and facades. The building is visually more diverse than the Back Bay's block; it has more diverse colors, more varied window positions, more types of textures, and it is certainly more fragmented. On the other hand, the Back Bay's block is much more sober; its colors are similar, the position of the windows is more regular, brick and stone are the dominant textures, and it is much less fragmented. However, in The Back Bay's block, we can clearly perceive different functional part—the buildings, whereas in Kroll's building we perceive many small parts—walls and windows, but we do not perceive them as functionally autonomous. For us, Kroll's building, despite its visual diversity still constitutes a single building. I argue that we tend to perceive the Back Bay as more diverse because of the functional autonomy of its parts.

Fig. 7.75
Le Corbusier, 1945-52
Unité d'habitacion à Marseille, France

Fig. 7.76
Informal settlement, 1980s, Portugal

The second example is a comparison between one of Le Corbusier's*unités d'habitation* (Fig.7.75), and a group of houses from an informal settlement (Fig.7.76). In the Le Corbusier's *unité,* the different dwellings despite being functionally autonomous units, are functionally very subordinate, to the aesthetical and formal order of the entire building.



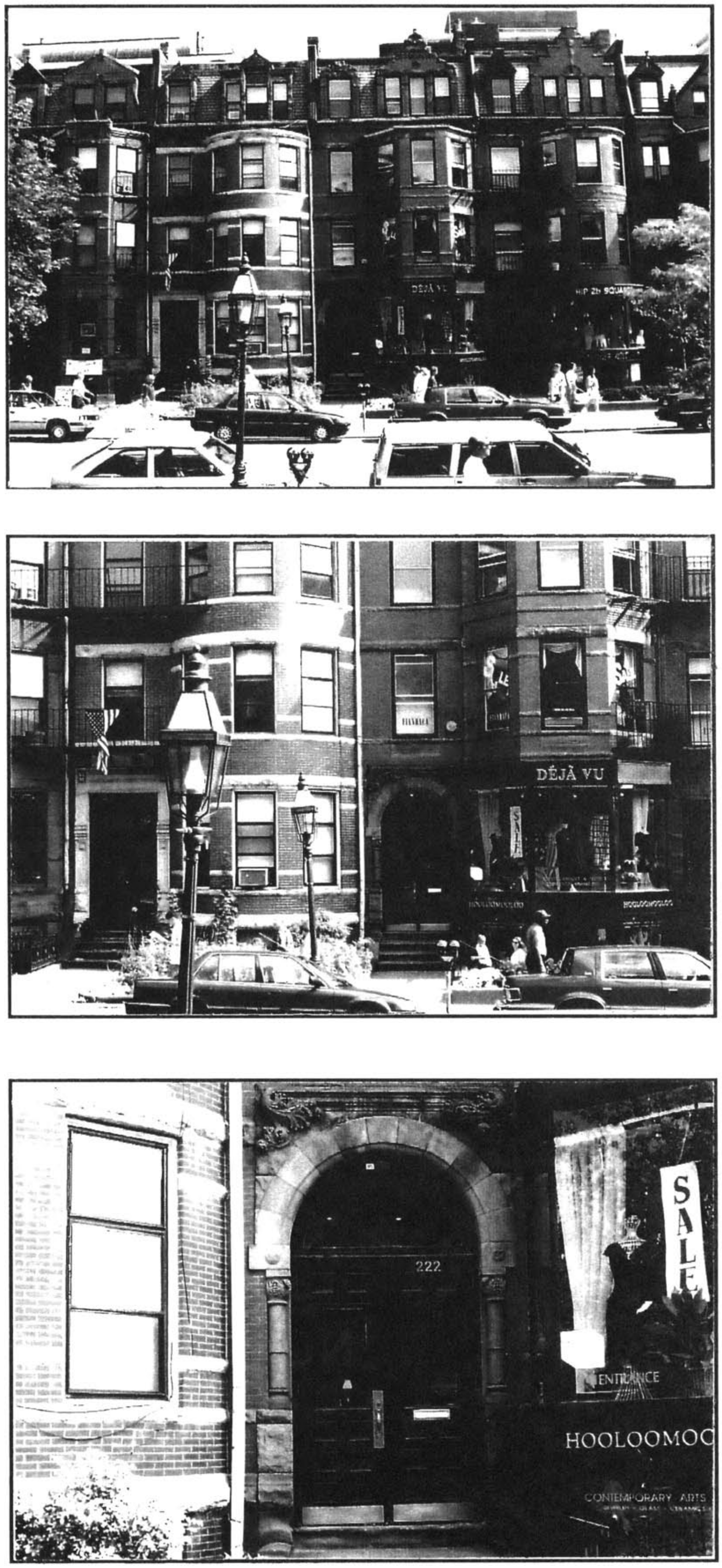


Fig. 7.84
Distance influences the perception of diversity in a urban environment. As the observer approaches urban artifacts, he is able to see new details, and so the perception of diversity reaches another level. The Back Bay, Boston, USA: a group of buildings (a), a building (b), and details (c)

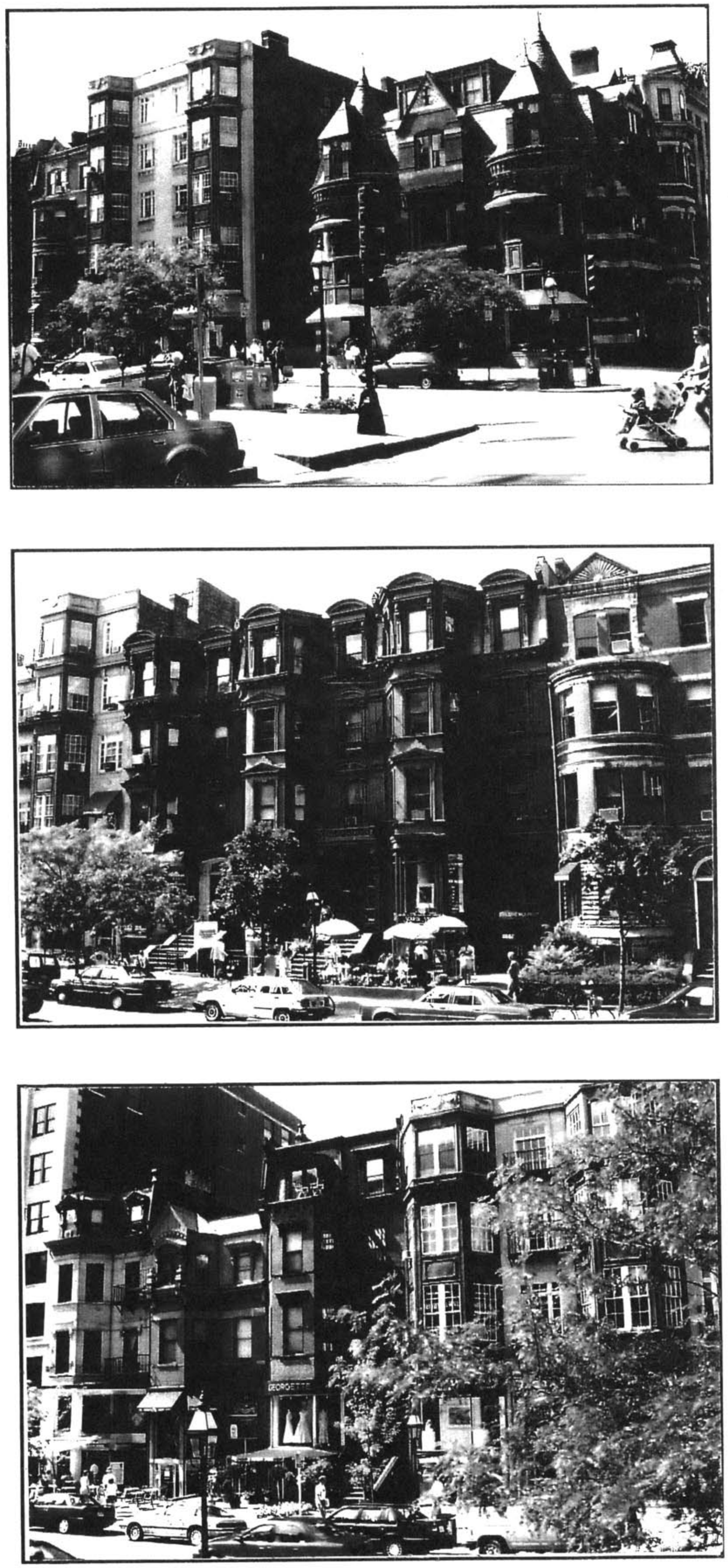


Fig. 7.86
Motion affects the perception of diversity in a urban environment. As the observer moves along a street he sees new artifacts, which can be similar or diverse from previous ones, and so influence his perception of diversity
The Back Bay, Boston, USA

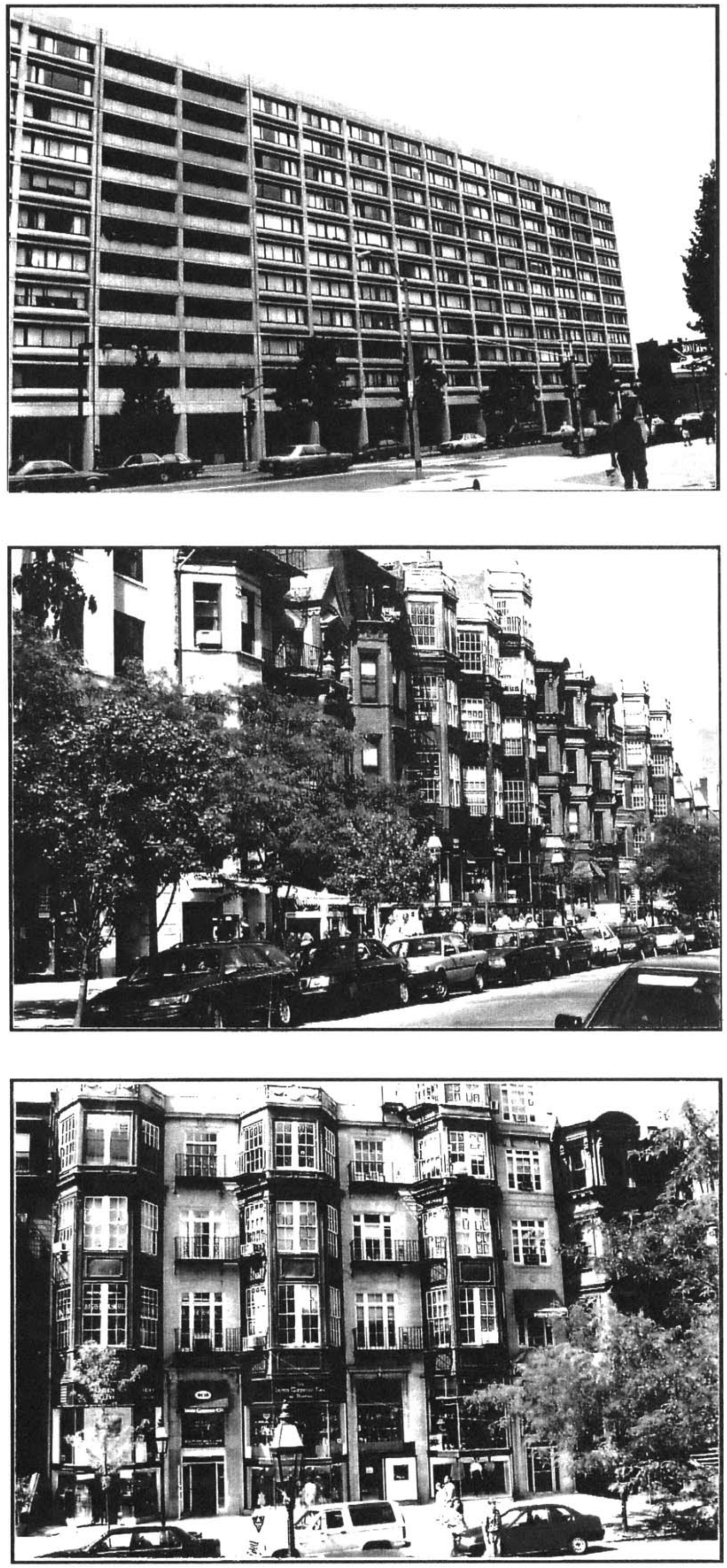


Fig. 7.88
Influence of 3D on the perception of diversity. The facades which are not the result of simple extrusion of a 2D drawing are more successful in terms of using three dimensions to enhance the perception of diversity. Building on Mass. Ave. (top), and buildings in Back Bay, Boston, USA